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Photographic Determinations of Stellar Masses

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1. *Introduction. Formula for total mass of a binary.*

The law of gravitation enables us to derive individual stellar masses for the case of binary stars, through appropriate observations of the orbital motion of the components. The details of the method are many and intricate. The purpose of this note is to outline the principles of the method and to describe the required observations. The attainable accuracy and limitations of the method will be discussed and some recent results will be presented.

Let A and B be the bright and faint components of a binary star. The *intrinsic* elements of the orbit are the period P, the eccentricity e and the periastron passage T, together with the semi-axis major a which determines the scale. For true binary stars, observations have revealed Kepler motion, *i.e.*, an ellipse relative to the focus, subject to the law of areas. From simple kinematical considerations it follows that in such a case the relative acceleration of the two stars (*i.e.*, the vectorial difference) amounts to

$$4\pi^2 \times a^3/P^2 \times 1/r^2, \tag{1}$$

where r is the radius vector. According to Newton's law of gravitation this relative acceleration is

$$G \times (\mathcal{M}_A + \mathcal{M}_B)/r^2, \tag{2}$$

where G is the constant of gravitation, and $\mathcal{M}_A$ and $\mathcal{M}_B$ are the masses of the two stars, assuming their mass composition to have spherical symmetry. Equating the two statements for the relative acceleration we find

$$\mathcal{M}_A + \mathcal{M}_B = 4\pi^2/G \times a^3/P^2. \tag{3}$$

Here the semi-axis major is expressed in centimeters, the masses in grams and the period in seconds of time. A convenient conversion to practical units is obtained by writing out formula (3) for the Sun-Earth system, and dividing this expression into (3). The dimensions of the physical constants are thus divided out and we may choose any units we please. By neglecting the Earth's mass and choosing as units the astronomical unit, the Sun's mass, and the sidereal year, we arrive at the fundamental formula

$$\mathcal{M}_A + \mathcal{M}_B = a^3/P^2. \tag{4}$$

The sum of the masses in a binary system is thus easily evaluated if

the scale a of the orbit and the period of revolution P can be found. This presupposes adequate knowledge of the apparent orbit and of our distance to the system as shown in section 2.

For the solar system each planet, in a sense, forms a binary system with the Sun as the principal component; formula (4) in this case represents Kepler's third Law.

2. *Relation between apparent and true orbit. Dynamical and orientational elements.*

The *apparent* orbit of a double star is obtained from observations of the relative position of the components made at different epochs. The accuracy of an apparent orbit is conveniently established by varying the orbital elements and studying the effect on the representation of the observations. Briefly the method is the following:[1]

The position of the fainter component relative to the other one is given for the true orbit in space by the radius vector r and the true anomaly v (counted from periastron); the equivalent polar coordinates for the apparent orbit on the sky are the separation d expressed in seconds of arc, and the position angle p counted from the north through the east. In what follows the observed relative position is studied through the rectangular coordinates Δx, Δy counted along and perpendicular to the direction of diurnal motion for a standard equator:

$$\begin{aligned} \Delta\alpha \cos\delta = \Delta x &= d \sin p \\ \Delta\delta = \Delta y &= d \cos p \end{aligned} \tag{5}$$

In photographic double star work Δx, Δy are obtained directly, while in case of micrometer work the observed d and p have to be transformed to the rectangular system.

The relation between the *true* orbit in space and its apparent projection on the plane perpendicular to the line of sight is found from the equations

$$\begin{aligned} d \cos (p - \Omega) &= r \cos (v + \omega) \\ d \sin (p - \Omega) &= r \sin (v + \omega) \cos i \end{aligned} \tag{6}$$

Here Ω is the position angle of the ascending node, i the inclination and ω the angle from ascending node to periastron counted in the direction of orbital motion. (5) and (6) lead to

$$\begin{aligned} \Delta x &= BX + GY \\ \Delta y &= AX + FY \end{aligned} \tag{7}$$

Formulae (7) represent a transformation of axes. X and Y are the rectangular coordinates in the true orbit, reduced to unit semi-axis major and measuring X along the major axis. A, B, F, G are the direction cosines of the axes in the true and the apparent orbits, multiplied by the semi-axis major expressed in seconds of arc; they are given by

$$\begin{aligned} A &= a (\ \cos\omega \cos\Omega - \sin\omega \sin\Omega \cos i) \\ B &= a (\ \cos\omega \sin\Omega + \sin\omega \cos\Omega \cos i) \\ F &= a (-\sin\omega \cos\Omega - \cos\omega \sin\Omega \cos i) \\ G &= a (-\sin\omega \sin\Omega + \cos\omega \cos\Omega \cos i) \end{aligned} \tag{8}$$

Apart from the semi-axis major a, the *orientational* elements A, B, F, and G are for the present purpose of observational significance only, while X and Y are related to the elements P, e, T which determine the time-space relation in the true orbit; the latter are referred to as the *dynamical* elements.

The relation of the dynamical elements to the rectangular coordinates X, Y in the unit orbit is given by the equations

$$\begin{aligned} X &= \cos E - e \\ Y &= \sqrt{1-e^2}\sin E \end{aligned} \tag{9}$$

Here E is the eccentric anomaly which is related to the mean anomaly M for epoch t by Kepler's equation

$$E - e\sin E = M \tag{10}$$

where

$$M = 2\pi\,(t-T)/P \tag{11}$$

Tables giving X, Y in terms of M expressed in degrees have been published by the Union Observatory.[2]

The procedure is to get hold of a provisional set of dynamical elements P, e, T derived for example by Zwiers' method,[3] and to derive the positional constants A, B, F, G. By varying the dynamical constants different sets of A, B, F, G are found and for each orbit a detailed inquiry can be made into the behavior of the residuals left by the observations. Since systematic errors are likely to play a role, primarily in the distances, a formal least-squares solution for differential correction is not necessarily preferred.

If the orientational elements are known, the scale a of the orbit and Ω, ω, and i are given by the relations:

$$\begin{aligned} \tan(\omega+\Omega) &= (B-F)/(A+G) \\ \tan(\omega-\Omega) &= (-B-F)/(A-G) \end{aligned} \tag{12}$$

$$\cos i = m/a^2 \tag{13}$$

where

$$a^2 = j + k \tag{14}$$

$$k = (A^2+B^2+F^2+G^2)/2,\ m = AG-BF,\ j^2 = k^2 - m^2 \tag{15}$$

With a value for the heliocentric parallax p, the semi-axis major can be converted into astronomical units

$$a''/p'' = a\ \text{(A.U.)} \tag{16}$$

Together with the dynamical element P, the sum of the masses is now found through formula (4)

$$\mathcal{M}_A + \mathcal{M}_B = a^3/P^2.$$

3. *Relative mass of the components. Apparent orbit. Mass function in case of invisible component.*

The distribution of the sum of the masses over the two components can be obtained by a comparative study of the orbital motion of the components with respect to their *center of mass*. This necessitates observa-

tion of either component with respect to stars not belonging to the system. This can be done with meridian circle, visual refractor (micrometer, heliometer), or by photography. Although in a few isolated cases valuable results have been obtained with the former methods, the photographic method has the advantage of permitting with adequate accuracy in many cases a simultaneous determination of the fundamental data: parallax, relative mass, (and proper motion).

The photographic measures are assumed to be made in a rectangular coordinate system oriented closely to the equatorial system. Assuming the components of the double star to be well measurable, *i.e.*, of appropriate exposure and well separated, the measurements give the following relations for the positions X_A, Y_A of the bright component:

$$X_A = c_x + \mu_x t + \pi P_\alpha - \mathcal{B} \times \Delta x \qquad (17)$$
$$Y_A = c_y + \mu_y t + \pi P_\delta - \mathcal{B} \times \Delta y$$

Here c_x, c_y is the position of the center of mass at the epoch $t = 0$; μ_x, μ_y is the yearly proper motion of the center of mass which is practically equal to $\mu_\alpha \cos\delta, \mu_\delta$; π is the relative parallax; P_α, P_δ the parallax factors in right ascension and declination. The fourth terms on the right side refer to the faint component; $\mathcal{B} = \mathcal{M}_B/(\mathcal{M}_A + \mathcal{M}_B)$ gives its mass in terms of the total mass; Δx, Δy define its position relative to that of the bright component, see also (6) and (7).

In order to make a satisfactory determination of $\mathcal{B}$ and π, a large number of observations X_A, Y_A is required, spread strategically in time. With sufficient variation in the coefficients Δx, Δy (and P_α, P_δ) the quantity $\mathcal{B}$ (and the parallax π) can then be derived from one or both coordinates. A curvature of about ″.5 in the relative orbit, and the equivalent of some 50 good plates give $\mathcal{B}$ with an accuracy of about 2%.

While in the ideal case, parallax and relative mass are thus furnished by photographic observations only, it will occur often that the faint component is not recorded separately, in which case the quantities Δx, Δy are taken from a relative orbit based on micrometer observations of the double. The diameter of the photographic image obtained with a long-focus instrument is about 2″ to 3″, and many a faint component will thus be blended with the primary. These cases are quite common and are, of course, a potential cause of restricted accuracy in any determination of relative masses. Approximate allowance can be made by assuming the position of the photographic image to correspond to the weighted light center of the two components. It is easily seen that the measured position of the blended image is closer to the center of mass, as given by the expression $\mathcal{B} - \beta$ instead of $\mathcal{B}$. Here β is the luminosity of the faint component in terms of the combined luminosity;[4] the relation between β and the magnitude difference Δm of the components is given by

$$\beta = 1/(1 + 10^{0.4\,\Delta m}) \qquad (18)$$

For this common case of determining relative masses we thus have

the formulae

$$X_A' = c_x + \mu_x t + \pi P_a - (\mathcal{B} - \beta)\,\Delta x \qquad (19)$$
$$Y_A' = c_y + \mu_y t + \pi P_b - (\mathcal{B} - \beta)\,\Delta y$$

which refer to the position of the light center instead of the primary. The quantity $\mathcal{B} - \beta$ which may now be derived can be approximately corrected for β, if a satisfactory observation or estimate of Δm is available.

In a few cases the available observations have been distributed sufficiently in time to derive the *apparent orbit* of the bright component. In this case, the formulae (17) are written as follows:

$$X_A = c_x + \mu_x t + \pi P_a - [\mathcal{B}\,B \times X + \mathcal{B}\,G \times Y] \qquad (20)$$
$$Y_A = c_y + \mu_y t + \pi P_b - [\mathcal{B}\,A \times X + \mathcal{B}\,F \times Y]$$

For the case of blended exposures, formulae (20) become

$$X_A' = c_x + \mu_x t + \pi P_a - [(\mathcal{B} - \beta)\,B \times X + (\mathcal{B} - \beta)\,G \times Y] \qquad (21)$$
$$Y_A' = c_y + \mu_y t + \pi P_b - [(\mathcal{B} - \beta)\,A \times X + (\mathcal{B} - \beta)\,F \times Y]$$

In the ideal case the observations would thus permit an analysis of the apparent orbit of the bright component (20) or of the center of light (21) with respect to the center of mass, by the same method as outlined for the relative orbit of the two components. In the present stage of this problem it is usually desirable for the completion of the results to adopt the dynamical elements P, e, and T from this relative orbit, or from the spectroscopic orbit obtained from observations of radial velocities. Each case will have to be considered on its own merits but it is well to keep in mind that a "complete" study will involve both astrometric and spectroscopic observations.[5]

A general solution by the method of least-squares gives then, in addition to c, μ, and π, values for

$$(\mathcal{B} - \beta)\,A,\ (\mathcal{B} - \beta)\,B,$$
$$(\mathcal{B} - \beta)\,F \text{ and } (\mathcal{B} - \beta)\,G,$$

β equalling zero for the case (20). From these are found the orientational elements Ω, i, and ω, which may be compared with values for these same elements found from micrometer or spectroscopic observations (except i in the latter case). The important result is $(\mathcal{B} - \beta)\,a$ which when compared with the a of the relative orbit gives a determination of $(\mathcal{B} - \beta)$.

* * * * * *

The foregoing considerations become of particular interest when the apparent periodic motion of a star is well established, but no companion has yet been observed because of its faintness or proximity or both. The classical examples are those of Sirius and Procyon, first studied by Bessel; modern photographic observations have made further progress. There is already Reuyl's discovery of the variable proper motion for Ross 614, while Strand has recently found several cases of perturbed Kepler motion in classical binary systems. This problem is particularly significant since it contains a potential method

for discovering planetary as well as stellar companions.[6]

From formula (21) it appears that for such an "astrometric" binary a complete analysis of the apparent orbital motion will eventually give the dynamical elements P, e, T, the orientational elements Ω, ω, and i, and the scale $(\mathcal{B} - \beta)\ a$, where a is the semi-axis major of the orbit of the invisible component with respect to the bright one. As long as the companion remains undiscovered, the sum of the masses cannot be found but only the *mass function*

$$(\mathcal{B} - \beta)^3\ (\mathcal{M}_A + \mathcal{M}_B) \qquad (22)$$

as follows from formula (4) which assumes the parallax to be known. The present method generally does, therefore, not permit the determination of the mass of the companion. But from formula (22) it appears that, with a reasonable assumption of the total mass, a value for the difference in relative mass and relative luminosity, $\mathcal{B} - \beta$, can be found. As long as the companion is not seen β remains unknown and we can then only make a statement as to the lower limit of $\mathcal{B}$ for the relative mass of the companion. If, however, the period were so long as to indicate a wide separation so that the component would be not blended with the primary, β could be ignored and a value of $\mathcal{B}$ derived, which would be only slightly affected by the uncertainties in the assumed total mass.

4. *Method of observation; measurement and accuracy.*

The ideal method for determining accurate stellar masses is photography with a long-focus refractor. The advantage of long focus is obvious both for photographic and micrometer observations. The latter require a visually corrected objective, which, with currently available photographic emulsions and filters, has also become most effective for photovisual astrometry.

In order to permit a comparison of the relative positions measured on different plates a reduction to a common origin, scale, and orientation is necessary. Generally a simple linear transformation is all that is needed and the reductions are carried out most effectively and economically by the use of Schlesinger's dependences.[7] Thence the reduced positions may be analysed by one of the methods described before.

A long-screw measuring machine is commonly used for measuring the plates and has been found both accurate and expedient. The method of measurement has no appreciable influence on the result, as long as fundamental precautions such as reversal of direction of measurements are taken. In any case, the main source of errors is inherent in the photographic exposures and remeasurement is generally, therefore, not necessary. Increase in accuracy can be obtained best by increasing the number of photographic exposures under adequate conditions.

The conventional photographic effective wave-length is usually between λ 4000 and λ 5000, and is strongly dependent on spectral type.

In photovisual photography the effective wave-length is close to the wave-length of minimum focus, which is about λ 5500. Now the atmospheric dispersion per 100 Å.U. at altitude 45° is given by[8]

$$-.00528/\lambda^2 - .000256/\lambda^4 \qquad (23)$$

where λ is expressed in microns. The dispersion decreases rapidly with increasing redness, and by using a yellow filter for a visually corrected refractor, the range in dislocation of the star images by atmospheric dispersion becomes small for different spectral types. With a photovisual combination at λ 5500 both Hertzsprung[9] and Strand[10] find an increase in effective wave-length of about 20 Å from spectral types A to K, which corresponds to a decrease in the refraction constant of only ″.007. In conventional photographic astrometry at about λ 4300, a change of 200 Å may exist for the same variation in spectral type, giving a difference in the refraction constant of over ″.1. The advantage of photography in longer wave-lengths is thus obvious. The erstwhile objections to the relative slowness of yellow sensitive emulsions do not hold any more, since the increase in speed in the photovisual range has been between 15 and 20-fold over the past twenty-five years.

The long-focus visual refractor enables us therefore to approximate a "monochromatic" portrayal of starfields on the largest possible scale, consistent with average atmospheric conditions. Photovisual photography thus reduces systematic color effects below a negligible level, a property first fully understood and exploited by Hertzsprung nearly thirty years ago. By the use of gratings or rotating sectors suitable magnitude compensation is provided to eliminate another source of systematic error. This thorough prevention and elimination of systematic magnitude and color effects permits an attempt at reaching high systematic accuracy by using a large number of exposures. Hertzsprung realized the importance of this for the case of wider double stars; the same procedure is clearly indicated for other fields of photovisual astrometry, like parallax and relative mass in the present problem. The inherent accuracy of a star position measured on a surrounding set of reference stars is given by a probable error of ″.03 for a good plate containing two or three consecutive exposures spaced apart by a few millimeters. The exact value of this quantity depends on the focal length and atmospheric conditions; it is clear that especially for short exposures during which unusually favorable atmospheric conditions are maintained, full advantage of a great focal length is obtained. There are on the other hand other factors involved like distortions in the films which are, of course, more serious for shorter focal lengths. However, by using small configurations of reference stars, or by using reversed exposures on the same plate, the distortion effects can be kept sufficiently small.

As an example we will give some data pertaining to the Sproul 24-inch refractor. The focal length is 36 feet, or more exactly 1093

cm, giving a scale in the focus of 1 mm = 18".87. The minimum focal length is at λ 5610. A minus-blue (No. 12) Wratten filter is used in front of the 5-inch by 7-inch plates. At present the Eastman Super Panchro Press emulsion is used for general work, giving an average effective wave-length of about λ 5800.

An alternate emulsion is the Eastman G-type, giving an average effective wave-length of about λ 5500. For either effective wave-length the focus is situated within a few tenths of a millimeter beyond the minimum focus, which is well within Raleigh's criterion for focal accuracy. According to the latter, all images secured within $4\,a^2\,\lambda$ of the focus of a theoretically perfect objective are equally good. In this expression λ is the wave-length that corresponds to minimum focal length, and a is the ratio of focal length to aperture. Schlesinger has found by trial with many objectives that the same criterion holds closely for photographs as well.[10] For the Sproul refractor $a = 18$, $\lambda = .00056$ mm hence Raleigh's limit is .7 mm.

The increase of effective wave-length between spectral types A and M amounts to about 75 Å for the Eastman super panchromatic plates and about half as much for the G-type plates, corresponding to changes in the refraction constant of —".023 and —".014, respectively.[11] These quantities are small but not always negligible and they emphasize the importance of adequate knowledge of the spectral types of the stars measured, particularly in case of a change of emulsion. For plates used on the general astrometric program at the Sproul Observatory a change from the G-type to the Eastman Super Panchro Press emulsion was made in the summer of 1939, because of the speed-ratio of 3 to 1 in favor of the new emulsion. The advantages of the higher speed seemed to outweigh the slight discontinuity in photographic portrayal just explained, and the latter can easily be corrected for when desired. For the extremely accurate work done on double star measurements the G-type emulsion is continued, since the exposure times are already sufficiently short.

The accuracy of a relative position measured on a good plate with two exposures taken with the Sproul telescope is given by a probable error of ".036 or about two microns.

5. *Results for stellar masses.*

Due to the very nature of the problem our present knowledge about individual stellar masses is in a heterogeneous state. The ideal mass determination involves a large parallax *(p)*, a good orbit *(P, a)*, and well separated components, and it is seldom that all three conditions are fulfilled simultaneously.

As an example[12] of a determination of stellar masses we take the case of τ Cygni *A, B*. This object has been photographed at the Sproul Observatory since 1912. Measures on 79 plates taken on 60 nights from 1912 till 1939 give a value of $+.316 \pm .013$ (p.e.) for $\mathcal{B} - \beta$; the

List of Stellar Masses

No.	Name	1900 R.A. h m	1900 Decl. ° ′	Visual Magnitude	Spectra	Parallax	Period in years	Semi-axis major	A.U.	Abs. vis. mag.		Masses	
											+5	1	
1	Sun				G0								
2	α Centauri *A, B*	14 32.8	−60 25	0.3 , 1.7	G4, K1	″761	80	17″.7	23.3	+ 4.7	+ 6.1	1.1	0.9
3	Sirius *A, B*	6 40.7	−16 35	−1.6 , 7.1	A0, A5	.381	50	7.62	20.0	+ 1.3	+10.0	2.2	1.0
4	Procyon *A, B*	7 34.1	+ 5 29	0.5 , 10.8	F3, ...	.295	40.2	4.26	14.4	+ 2.9	+13.2	1.4	0.4
5	61 Cygni *A, B*	21 2.4	+38 15	5.6 , 6.3	K5, K6	.294	720:	24.64:	84.	+ 7.9	+ 8.6	0.6:	0.6:
6	Krüger 60 A, B	22 24.5	+57 12	9.8 , 11.3	M4, M6	.256	44.5	2.36	9.2	+11.8	+13.3	0.26	0.14
7	o^2 Eridani *B, C*	4 10.7	− 7 49	9.2 , 10.7	B9, M5e	.205	248:	6.89:	34.	+10.8	+12.3	0.4	0.2
8	70 Ophiuchi *A, B*	18 0.4	+ 2 31	4.3 , 6.0	K1, K6	.196	87.8	4.56	23.3	+ 5.8	+ 7.5	0.90	0.73
9	η Cassiopeiae *A, B*	0 43.0	+57 17	3.6 , 7.4	F8, K5	.180	526:	12.53:	70.	+ 5.0	+ 8.7	0.73	0.45
10	ξ Bootis *A, B*	14 46.8	+19 31	4.8 , 6.8	G5, K5	.147	150.0	4.88	33.2	+ 4.9	+ 4.9	0.88	0.75
11	ξ Ursae Majoris *A + a, B + b*	11 12.9	+32 6	4.5 , 4.5	F9, F9	.123	59.86	2.54	20.7	+ 4.8	+ 5.2	1.1	1.3
12	ζ Herculis *A, B*	16 37.5	+31 47	3.1 , 5.9	G0, ...	.113	34.4	1.35	11.9	+ 3.4	+ 6.2	0.86	0.58
13	85 Pegasi *A, B*	23 56.9	+26 33	5.9 , 9.4	G0, ...	.099	26.46	0.82	8.3	+ 5.9	+ 9.4	0.35	0.37
14	γ Virginis A, B	12 36.6	− 0 54	3.65, 3.68	F0, F0	.089	171.4	3.75	42.	+ 3.4	+ 3.4	1.2:	1.2:
15	β 648 *A, B*	18 53.5	+32 46	5.4 , 7.1	G0, ...	.061	61.8	1.24	20.	+ 4.3	+ 6.0	1.2:	1.0:
16	9 Argus *A, B*	7 47.1	−13 38	5.7 , 6.4	G2	.059	23.18	0.58	10.	+ 4.5	+ 5.2	0.9:	0.9:
17	τ Cygni *A, B*	21 10.8	+37 37	3.8 , 6.6	F0, ...	.047	49.8	0.85	18.	+ 2.2	+ 5.0	1.5:	1.0:

separate results from the two coordinates are $+.319 \pm .027$ (x) and $+.315 \pm .015$ (y). The coefficients Δx and Δy in eq. (19) were taken from van Biesbroeck's orbit

($P = 49^{y}.8$, $a = 0''.85$, $e = 0.24$; $A = +''.582$, $B = +''.336$, $F = +''.586$, $G = -''.532$). A similar solution from 53 plates taken on 32 nights with the McCormick refractor,[13] gave $\mathcal{B} - \beta = + .349 \pm .022$, in excellent agreement with the Sproul value. For further use the value $\mathcal{B} - \beta = .32$ is used. With Kuiper's photometric determination of $\Delta m = 2.82$ we derive $\beta = .069$ and hence $\mathcal{B} = .39$. Adopting an absolute parallax of $+''.047$ the sum of the masses is found to be 2.5 $\odot$ so that the separate masses $\mathcal{M}_A = 1.5$ $\odot$ and $\mathcal{M}_B = 1.0$ $\odot$ are obtained.

In the accompanying table are given the results for some of the more accurate mass determinations. The extent of the list is limited primarily by the parallax. An attempt has been made to be more or less complete down to a limit of $0''.1$ for the parallax; some reasonably well determined masses at greater distances are included.

NOTES ON THE TABLE:

1. The parallaxes in this list are of comparable accuracy, the average probable error being about $''.005$. Attention is drawn to the rapid decrease in accuracy of the total mass with decreasing parallax; an error of 10% in parallax corresponds to an error of over 30% in the total mass!

2. The orbital elements are somewhat uncertain for 61 Cygni and η Cassiopeiae.

3. The mass-ratios for 61 Cygni and o^2 Eridani B, C are provisional.

4. The accuracy of the mass-ratio is lessened by blending of the components for ξ UMa, ζ Her, 85 Peg, 9 Arg, β 648, and τ Cyg.

5. ξ UMa is a binary whose components are again binaries of shorter periods. The masses given in the table thus refer to these two component binaries.

6. Photoelectric observations made by Hall indicate spectra of G5, M, and K5 for the faint components of ζ Her, 85 Peg, and β 648, respectively.

7. α Cen A, B, o^2 Eri B, C, and τ Cyg A, B are members of triple systems.

8. There are several binaries of large parallax for which the orbital elements are indeterminate and some time will have to elapse before masses can be derived. The two most obvious cases are:

Σ 2398 A, B, ($18^{h}\,41^{m}.9$, $+59°\,29'$; 8.9 — 9.7, M4-M5, p = $''.284$)
Groomb. 34 A, B (0 12.7, $+43\ \ 27$; 8.1 — 10.9, M1-M6, p = $''.278$)

Earlier results may be expected for Ross 614 and Wolf 424. The duplicity of the former is established through a perturbation in the photographic positions; so far no accurate orbit is available and the companion has not yet been observed ($6^{h}\,24^{m}.3$, $-2°\,44'$, 11, 13?, M2e, p = $''.262$). Wolf 424 A, B is a close double whose separation is $1''.1$ and whose orbital motion bears close watching ($12^{h}\,28^{m}.4$, $+9°\,34'$, 12.6 — 12.6, M8, p = $''.214$).

9. There are several binaries for which fairly accurate masses will become available within the next decade, (for example: 99 Her, 26 Dra, δ Eql, κ Peg, Ho 212).

10. Strand has recently found evidence for third, invisible, components in the 61 Cygni and ξ Bootis systems.

The masses in the present list are probably among the most accurate ones known. The results are valuable in demonstrating the small dispersion in stellar mass. The highest value is found for Sirius A (2.2 $\odot$), the smallest stellar mass known is that of Krüger 60 B (0.14 $\odot$). It is interesting to reflect that the largest known planetary mass is that of Jupiter (0.001 $\odot$) and the attempt at filling the gap between these is of the greatest observational interest. It should be mentioned that Strand's invisible component in the 61 Cygni system seems to have a mass of about 1/60 that of the Sun![14] Another important result is the correlation between mass and luminosity with the exception of the white dwarfs

(Sirius *B*, o^2 Eridani *B*, Procyon *B*?). It will probably be only a matter of years when for some of the nearby "single" stars perturbation may be found, which eventually may lead to an extension of the list of binaries of large parallax; these would be important for determining additional stellar masses. Sirius and Procyon were the first classical cases, Ross 614 the first photographic case, and more are likely to follow. It should further be understood that some of the component stars in the table are double (ξ UMa $A + a$, ξ UMa $B + b$) and that more may be found double in the future.

The present table is, of course, the result of very strong observational selection. Even with more data it will be very difficult to get a representative set of masses of the stars in general.

For the stars in the present list considerable improvement can be made through more intensive photographic observation, than has been the case so far. It is difficult to lay down general rules but the necessity for vastly superior parallax determinations should be emphasized. These can be reached by making observations at more than one observatory, but also by increasing the number of plates beyond the conventional 20 to 30 plates. There is no reason not to use a tenfold number and reach a probable error of ″003; it will then become advisable to use spectroscopic parallaxes for the reference stars in order to obtain an equitable reduction to absolute parallax.

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SPROUL OBSERVATORY, SWARTHMORE COLLEGE, SWARTHMORE, PENNSYLVANIA,
1943 MARCH 25.

A Construction Substitute for Pi in the Great Pyramid

By GEORGE M. McCONKEY and W. CARL RUFUS

Mr. John Taylor is credited with inventing the fanciful idea that the builder of the Great Pyramid of Cheops intended to record in its proportions important religious and scientific doctrines, not for the benefit of his contemporaries, but to be revealed to posterity four thousand years later. Professor C. Piazzi Smyth advocated the scientific side and ingeniously uncovered, concealed in the dimensions, advanced mathematical knowledge, including the value of π, also exact astronomical data, such as the diameters and distances of the Sun, Moon, and planets. The astronomical implications were further developed by Joseph Baxendall and others, until each trivial measurement, even of the ante-chambers of the pyramid, had mystical cosmic significance. The astronomer, Richard A. Proctor, assigned astrological significance, prob-

ably through Chaldean influence, rather than pure scientific aim, as the purpose of design in this great structure.

We reject these ideas and propose a new explanation of the fundamental mathematical relationships found. More specifically, construction principles are proposed which do not involve the knowledge and intentional use of an accurate value of π.

Ancient writers have left little material of basic significance to assist modern scientists in an attempt to interpret the numerical relationships that exist among the dimensions. One interesting and important item is attributed to Herodotus: The area of each of the four faces is equal to a square having its sides equal to the height of the pyramid. By accepting this statement as a starting point, we have the mathematical basis for the explanation proposed. Let $2b =$ base, $h =$ height, and $s =$ slant height, then $bs = h^2$, or $b:h = h:s$. The principle of the mean proportional which is involved, or its equivalent, similar triangles, may be used instead of the assumption of π as we demonstrate later.

Many modern measurements have been made on the Great Pyramid, which unfortunately have not been entirely consistent. Two items are here accepted,—the mean of the four sides of the base, 9069.5 inches, and the angle of slope, 51° 50′. As the royal cubit was about 20.6 inches, the base was probably intended to be exactly 440 cubits square. The cotangent of the angle, 0.7860, and half-base, 220 cubits, give a height approximately 280 cubits. We adopt these values in tens of cubits for the base and height, 440 cubits and 280 cubits, respectively. In this respect we follow an example given in the Rhind papyrus,—a pyramid with side 360 cubits and height 250 cubits.

Using the method of the given example in the papyrus we compute the *batter*.[1] Reckon with 280 to find one-half of 440 or 220. ½ of 280 is 140, ¼ is 70, and 1/28 is 10, making 220. That is, for one cubit rise the stones must be drawn in ½ + ¼ + 1/28 of a cubit. To reduce to *palms* multiply by 7 which gives 3½ + 1¾ + ¼ or 5½ palms. To reduce to *fingers* multiply by 4 which gives 22 fingers. The batter for one cubit rise is therefore integral, 22 fingers, and avoids troublesome mixed numbers.[2] The cotangent of the slope then becomes 22/28 or 0.7858, which is in good agreement with the angle of slope obtained by measurements.

During construction the problem would also be met to find the rise accompanying one cubit drawn in toward the center. This may be done as follows, using the Egyptian method based on the preceding batter. For each finger added to 22 toward the center must be added 28/22 or 1 3/11 to the height 28. This must be done 6 times to increase 22 to 28. So we have $28 + 6 \times 1\ 3/11 = 35\ 7/11$ fingers. If this is done in one

[1] The batter is equivalent to the distance to draw in a layer of stone which has a height of one cubit.

[2] This result was of course anticipated, as the height 280 cubits contains the factor 28 which is the number of fingers in one cubit.

step it is equivalent to the principle of similar triangles. $22:28 = 28:h'$. From which as before $h' = 35\ 7/11 = 35.6364$ fingers or 1.2727 cubits. Here a mean proportional or its equivalent, similar triangles, is involved from the standpoint of construction, as well as independently from the statement attributed to Herodotus, and support is found for adopting it instead of the assumption of π.

No example of square root is found in the Rhind papyrus, although the idea is said to be included in some early Egyptian works. It is quite significant to point out the close agreement between the quantity just found (the rise for one cubit draw) and the slant height for one cubit rise, which is another practical problem met in cutting the stones with triangular ends for filling, in order to make a plane sloping surface, and especially in covering the rough exterior with a finer grade of material more smoothly finished. This may be rationalized by later algebra and geometry. By the Pythagorean principle we have

$$s = \sqrt{(28^2 + 22^2)} = 35.6090 \text{ fingers.}$$

This differs only 0.0274 fingers or 0.001 cubits from the preceding value of h'. That is, the slant height for one cubit rise is very nearly equal to the rise for one cubit drawn in. Such a common length would have practical value in construction work. Perhaps the Egyptian architects overlooked this small difference or considered it so insignificant that it could be neglected in cutting pyramid stones. Or it may be that they obtained a value geometrically that would empirically satisfy both relations. In either case we have the two condition: $b:h = h:s$, and $s^2 = h^2 + b^2$. From which

$$s = b(\tfrac{1}{2}\sqrt{5} + \tfrac{1}{2})^* = 1.6180b.$$
$$h = b\sqrt{(\tfrac{1}{2}\sqrt{5} + \tfrac{1}{2})} = 1.2720b$$
$$s = h\sqrt{(\tfrac{1}{2}\sqrt{5} + \tfrac{1}{2})} = 1.2720h$$
$$b/h = \sqrt{(\tfrac{1}{2}\sqrt{5} - \tfrac{1}{2})} = 0.7861$$

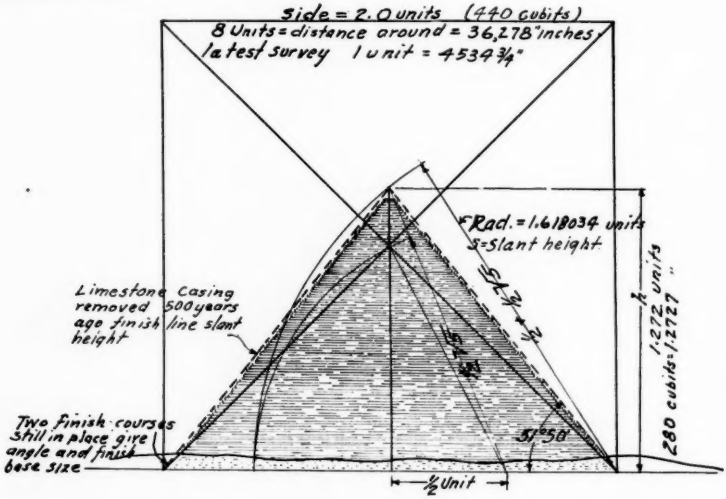
The length $\frac{1}{2}\sqrt{5} + \frac{1}{2}$ may easily be constructed geometrically and may have been used by the pyramid builders. $\frac{1}{2}\sqrt{5}$ is the hypotenuse of a right triangle with sides $\frac{1}{2}$ and 1 using any arbitrary unit, *e.g.*, one cubit in general or *b* in the pyramid. Adding $\frac{1}{2}$ to this length gives the desired value. (See diagram.)

The quantity, b/h above, 0.7861, agrees with the cotangent of the angle of slope, 0.7860. Also for $b =$ one cubit in the above expressions for s and h in terms of b, it is readily seen that $h = \sqrt{s}$. The square root is here involved, but the method of extracting the root is not used. Furthermore, for $h = 1$ cubit in the second expression for s above, $s = 1.2720$ cubits or 35.616 fingers, which lies between the two values above assumed to be equal. To obtain the entire slant height this must

*The quantity $\frac{1}{2}\sqrt{5} + \frac{1}{2}$ has interesting properties. Let it be represented by *a*, then $a^2 = a + 1$. Higher powers may be obtained readily by successively multiplying each side by *a* and evaluated by results previously obtained. Or the higher powers may be obtained in terms of *a*.

be taken 280 times, giving 356.16 cubits, differing only 0.07 cubits or about 1½ inches from the entire slant height by the Pythagorean formula.

Without using the value of π we have attempted to explain relationships between certain dimensions of the Great Pyramid, applying methods known to the Egyptians, with the added assumption that they accepted for practical purposes the equality of two lengths, which differ very slightly, or that they obtained, by an empirical method, a better value to adopt.


Side = 2.0 units (440 cubits)
8 Units = distance around = 36,278 inches
latest survey 1 unit = 4534¾"
Rad. = 1.618034 units
S = Slant height
Limestone casing removed 500 years ago finish line slant height
Two finish courses still in place give angle and finish base size
51°50'
1.272 units
280 cubits = 1.2727 "
½ Unit

PLAN AND ELEVATION
GREAT PYRAMID

From the fundamental relationship established between these basic dimensions, other mathematical relationships necessarily follow; so all additional coincidences discovered are entirely fortuitous and add nothing to the assumption of design. For example, another interesting relationship is that the ratio of the height to ½ the diagonal of the base is approximately 9 to 10. $h:b\sqrt{2} = 9:10$, from which $h = 1.2727b$, which agrees very closely with the preceding result, $h = 1.2720b$. This apparently has no special cosmic significance, and is introduced merely to illustrate the fact that many mathematical relationships may be deduced.

A multiplicity of other discovered relationships may be similarly explained. By accepting as the intended location of the pyramid, latitude 30° N, ($\sin 30° = ½$), advocates of concealed quantities found many additional inter-relationships and coincidences by using the factor ½.

By these methods the number of revealed quantities increased without limit and were assigned scientific and cosmic significance by the credulous.

Specifically π in the pyramid has not been used in this article, but its value is inherent in the problem on the basis of the discovered relationship that the height of the pyramid is the radius of a circle whose circumference is equal to the perimeter of the base. According to modern measurements there seems to be no question regarding this relationship; the question is, did the architect put it there intentionally, by chance, or otherwise? We submit a construction substitute for the intentional use of π. By applying the principle just stated we can find a value of π. For ½ base = b, and h = height, $2\pi h = 8b$. By b/h previously found, 0.7861, $\pi = 3.144$. Or using 440 and 280, respectively, for base and height $\pi = 3\ 1/7$.

In the Egyptian method of computing the area of a circle, although a value of π was not used, it is again inherent and may be found by applying later geometry. The rule was: Subtract 1/9 of the diameter from the diameter and multiply the remainder by itself. That is

$$(8/9 \times 2r)^2 = 3.160r^2.$$

This value of π, 3.160, does not agree very closely with the π of the pyramid, and gives no support to the idea that its builders knew and used an accurate value of this transcendental number.

In conclusion, it is conceivable, though improbable, that the Egyptian architects intended to incorporate in the construction of the Great Pyramid both of the principles considered in our discussion, the mean proportional and the value of π. If only one was used (and either one alone would be sufficient), it seems more probable that the mean proportional or its equivalent, similar triangles, accords better with their mathematical knowledge and building method. It is also supported by the statement attributed to Herodotus.

University of Michigan, December 23, 1942.

Telescopic Magnification and Eyepieces

By H. B. RUMRILL

With all that has been published on this most interesting topic, it appears to the writer that a good deal more might be added to our store of information concerning the lens systems that are barely secondary in importance to the object glass or mirror in the magnification of celestial objects.

A superb object glass, of ideal figure and beautiful polish, invites equal quality of the lenses used to magnify the focal image, the degree of perfection of which fixes the extent of ocular power in so far as the transmitted light and the state of the atmosphere allow. It is here that

the magnifying powers of the telescope do not as a rule parallel those of the microscope, for with the former there must always be regard for that outer shell of the Earth which envelopes it as with a screen—varying in transparency from time to time and in different places or at diverse heights, yet here and there sometimes so limpid as to seem almost nonexistent. The writer shall not forget Dr. Hubble's despairing exclamation as we were *attempting* to see the tremulous Martian features (at low altitude in the summer of 1939) through the 100-inch reflector at Mount Wilson: "If we could only bore a hole through the atmosphere!"

The limitations of telescopic power have been dealt with critically in many of the astronomical books, which, however, concur principally on the general utility of low and medium powers—say between 10 and 40 per inch of objective opening or "aperture." Possibly optical mathematics *prove* the inapplicability of much higher ratios than these, but, beyond question, experience is the best guide for the competent observer. So many elements enter into consideration, including variations in eyesight, along with all sorts of "seeing," that it is quite untenable to be dogmatic in the matter.

As an instance the writer well remembers that he was unable to separate the remarkable lines (about 50,000 to the inch) of the diatom *Pleurosigma Angulatum* with a lower power objective than a 1/6-inch, where his father succeeded with a 1/5-inch. Yet the latter, accustomed only to the microscope, failed in the detection of minute sunspots with a power sufficient to show them—each case evidencing the need for specialized eye training. The observation of double stars affords probably the best illustration of this factor, while planetary details are likewise a test of observational capacity.

In what follows (which is very far from exhausting the subject) it is assumed that the telescope mounting is rigid enough to resist vibration when focussing accurately a power of not less than 75 to the inch. This is wherein many portable telescopes "break down," their frequently unstable construction acting as a deterrent to the use of even medium magnification. The writer is in earnest, having learned in practical ways the essentials that promote satisfactory observation with small telescopes. It is possible to design a light mounting that is firm *except when moving the tube or adjusting the focus;* but why should mere portability be given undue preference when ordinary handling disturbs the position of the image in the eyepiece while using even the lower powers? The thing of real consequence is the result one is striving for.

When the observer has known the pleasure of focussing a power of 300 or more without perceptible tremor, any additional weight in the mounting that contributes to such quietude of performance may represent trouble and money invested to good purpose. The microscopist would not tolerate a tithe of the bother that many users of telescopes

put up with. A well-proportioned, substantial stand is therefore taken for granted, along with serious intention in the employment of the instrument, for the noble study of Astronomy assuredly demands devotion to the best means of cultivating its pursuit. (The writer recalls one who could "see" the outlay of cash for a billiard table but, while liking Astronomy, balked at the expense of a good telescope.) The observatory equatorials are not called into question in dwelling on these points, the fortunate individuals who have access to them belonging to that small minority of the disciples of Urania who are spared all such petty annoyances.

There is considerable diversity in both the formula and quality of the Huyghenian "negative" eyepiece, still the most common form of magnifier, notwithstanding the development of other lens combinations more suitable for some purposes. In its best estate, with correct proportions of curvature of the eye- and field-lenses, together with "stops" properly positioned, it is only second in general utility to such constructions as the Steinheil "monocentric" and the Zeiss "orthoscopic," as well as the "3-lens" eyepiece of the Hastings-McDowell design. The last named represents a material improvement over the old Kellner form, itself superior in turn to the Ramsden eyepiece wherein the curves of the plano-convex lenses face each other. One of the writer's finest Huyghenian eyepieces is an admirable specimen of the Clark 1.2-inch made under the direction of Mr. Lundin, and which for clarity of view would be difficult to excel.

The Clark form, too, is very convenient in having the eye-lens mount so made as to allow the easy use of cap screens interchangeably, which is also the case with those made by Cooke & Son (later Cooke, Troughton & Simms), of York, England. Because of this advantage the writer adopted the Clark style of cap in the mounting of a number of screen glasses of various absorptions and colors.

At this point it might be mentioned that to a great degree interchangeability has been overlooked or discounted by some of the leading manufacturers, unfortunately too often for selfish reasons. Good old Doctor Brashear endeavored once to interest other instrument makers in the use of uniform eyepiece tubing, for a like desirable purpose that nearly a century ago led to the adoption of the "Society" screw thread in the mounting of microscope objectives,—but with little success. He had selected a tube diameter of 1¼ inch, of wall thickness 3/64 inch, and with a screw thread of 40 to the inch, as a standard for eyepieces other than those of unusually wide field. The Cooke tube is 1 3/16 inch, the Clark 1⅛—both of thinner wall than the Brashear; while a 1 inch, or diameters very slightly under or over, are largely in use by a number of makers. Even with the action alluded to on the standard screw thread for microscope objectives, their makers have never united on a uniform tube diameter for eyepieces.

Most certainly, in the present state of scientific instrument manufacture, selfish and other considerations might be subordinated to the desirability of a standard (with suitable "adapters" for telescopes that do not conform), especially as "shop testing" methods have long made it feasible to attain uniformity and interchangeability in many other directions. This need not affect the maintenance of the manifold lens curvatures that have been carefully calculated, often traditional with opticians, and which commonly do not follow exactly the simple aliquot divisions of an inch. Incidentally, an occasional cause of complaint has been the over-stating of eyepiece magnification—by no means a modern fault, for it is a practice of long standing even with respectable opticians. In the writer's collection is a well made Huyghenian eyepiece engraved on the cap "1/5," but which is actually of less power than a quarter-inch.

Usually, the older Huyghenian eyepieces were of rather narrow field, notably those made for the "dialyte" telescopes by Plössl, of Vienna. The broader field of the Ramsden "positive" eyepieces has, however, been gradually approached in the "negative" construction, and the latter as now made by the leading opticians are not deficient in this respect within the limitations of their formulae. Much of the difference between simple and compound eyepieces, though, is evident mostly to the expert eye,—but then so are the finer planetary details. The French Huyghenian eyepieces, such as those of Bardou, have the field-lens mounted in a sliding inner tube, allowing *reduction* of magnifying power; yet a somewhat doubtful advantage, as it is optically preferable to maintain precise relationship between field- and eye-lenses, relying on a set of eyepieces in normal condition for scaling the powers.

As in the case of the best modern microscopes, it is quite practicable to have a small "battery" of telescope eyepieces so constructed as to push "home" to a common focus in order to avoid the continual turning of the focussing wheel, backward and forward, when changing powers. To accomplish this with a set of Huyghenian eyepieces ranging from 1 inch to ¼ inch, the writer found a very simple solution in a number of short collars cut from a piece of closely fitting adapter tube (as recommended by the English astronomer W. S. Franks). These slide pretty tightly over the eyepiece tubes, forming a secondary shoulder at a point which must be determined by trial. One improvement in construction that favors this method is the provision of longer tubes with deep field-lens cells for the higher powers. Burnham, in "Astronomy for Amateurs," described many years ago how he accomplished this purpose by using tightly fitted rings of tinplate, filed to higher points on opposite sides—a much more troublesome expedient, however, than the former when arranging a set of oculars in parfocal adjustment. Either device is of course mostly applicable to eyepiece sets of similar formulae, negative or positive.

Breadth of field is an important feature, as between the wide fields

so attractive when viewing groups of stars, and the narrow fields that aid in looking at double and multiple stars, or the planets. The first are seldom wide enough for the spread of the Andromeda nebula and are possibly at their best with the Pleiades and the Praesepe, or other coarse clusters, under the lowest powers; the Perseus cluster requiring greater magnification. In all these phases of observation there enters something of the element of "personal equation," resting largely on the education of the eyes. Happy the observer whose sight is normal and not afflicted with such baneful defects as astigmatism or any fault that may lead to erroneous impressions. The history of Astronomy records examples of especially keen vision, although possibly many could be found who can emulate such competence in this regard as distinguished Sir William Herschel, Dawes, Webb, Burnham, Denning, Barnard, and other eminent observers of the past.

The relation between objective and eyepiece varies greatly with the character of the object under scrutiny, hence the advisability of purchasing a comprehensive range of powers, following the recommendation of Garrett P. Serviss in "The Pleasures of the Telescope," to "get six or eight, or a dozen" (the writer has many more than that, of the different constructions by makers of repute, picked up now and then during nearly forty years of active observation). To this might be added suggestions in line with the purport of the present article.

One of the "talking points" of the old Steinheil "monocentric" oculars is absence of inner reflections (such as may produce an exquisite miniature, or pseudo-satellite, of Venus, or possibly of other planets). Its field is somewhat broader than that of the "solid" eyepieces, although the latter are similarly free from reflections and to be preferred for the higher magnifying powers, but at their best within a restricted central zone. Among others a ⅓-inch by Brashear and a ¼-inch by Tolles are part of the writer's equipment, the Tolles lens especially fine. The association of such perfect lenses with an object glass of the "first water" is capable of yielding the utmost satisfaction when the other requisites—mounting, atmosphere, observer's eye—are on a parity with them.

On the other hand, telescope object glasses and other lenses of indifferent quality can easily conduce to imperfect conceptions of celestial objects, being in the same category as the cheap microscopes, of which the prominent New Jersey naturalist, Dr. Alfred C. Stokes, once warned that, if nothing better could be afforded, it might be an unkind fate to do without them, "but is not life itself hard?" A two-inch telescope in the writer's possession has objective and ocular well mated, *at the wrong end of the quality scale,* along with a red screen for viewing the Sun—a wretched "complex" of inferiority—but it is an anonymous production and a good example of what a telescope should not be.

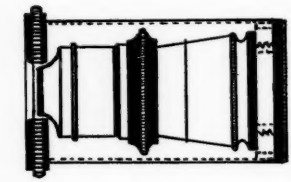
For sheer ineptitude of statement of the functions of object glass and

eyepiece, the following is cited from Smith's "Illustrated Astronomy"—on old "stand-by"—which seems, almost unbelievably, never to have been challenged:

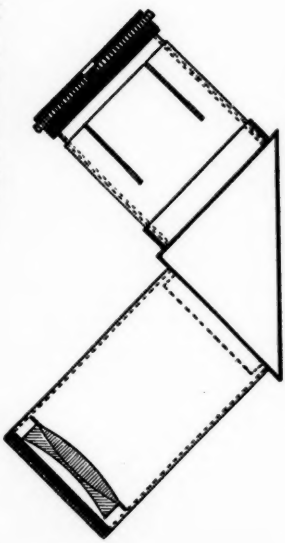
> The magnifying power of a telescope depends altogether on the eyepiece. The only use of large object glasses is to furnish light enough for eyepieces of great magnifying powers.

Well might "Alice in Wonderland" remark "wronger and wronger"—

Parfocal arrangement of five Huygenian eyepieces: four with collars attached, on a line with lower rim of eye-cap of 1/4-inch eyepiece.



Tolles 1/2-inch microscope objective mounted in standard Brashear 1 1/4-inch tube for use as an eyepiece.



"Barlow" amplifying lens as applied to diagonal prism, the eyepiece sliding in the adapter to vary the power. Distance between lens systems 5 to 6 inches.

NOTE: The outer surfaces of the achromatic negative lens may also be plano-concave.

for beyond doubt its author could hardly have had more than a smattering of the properties of lenses, much less any knowledge of Optics.

An essential feature, upon which eye-comfort depends, is the space in front of the eye-lens to what is known as the "eye-point." Certain eyepiece formulae necessitate holding the eye very close to the eye-lens; others, as the "orthoscopic," also the "periscopic" of Gundlach, are much easier to use, but require exactness in both distance and diameter of eye-cap opening. As made by Zeiss, the "orthoscopic" permits the comfortable use of screen glasses, particularly of the sliding double wedge (which takes up appreciable room between eyepiece and eye), so helpful in studying the solar surface or that of the Moon. These types also lack the disagreeable effect when looking at such bright objects, due to the focal plane being immediately back of or touching the field-lens of some of the positive eyepieces, and disclosing the consistence of the glass.

The "pancratic" terrestrial eyepiece—with latitude in magnifying power by simple alteration of the interval between the erecting lenses and those next to the eye—enables nicety in adjusting power to light value, but with the disadvantage of undue length of drawtube between focussing mechanism and the eye. For terrestrial use on telescopes of apertures above two inches, it is more convenient to apply the prismatic erecting arrangement in conjunction with low power inverting eyepieces.

Having experimented with some of these pancratic combinations, the writer feels that for astronomical observations there is too little acquaintance with the old-fashioned so-called "Barlow" lens, or amplifier, which augments and varies telescopic power by its interposition between object glass and eyepiece, thereby extending effective focal length, but naturally having its range limited by the amount of light passing through the object glass. Where there is sufficiency of light it may prove a serviceable adjunct, as testified by some of the older observers like Dawes and Denning, who wrote convincingly of its capabilities. For the best effects it is obligatory that the "Barlow" lens be an aplanatic combination in order to transmit unimpaired the image formed by the object glass. Its chief function is increase of *amplification* of the lower power eyepieces, so much more pleasant to use than those of high power, whose equivalent they thus become.

A chance remark by Dr. Brashear to the writer, that a microscope objective makes a good telescope eyepiece, led to a number of trials of such objectives, with results that more than sustained his assertion. The secret is to place the objective with its front lens next the eye—in other words in reversed position—with an appropriate eye-cap. A Zeiss 17-mm. and a Spencer 1-inch, both of moderate field, so mounted gave excellent definition, better than that of the ordinary eyepieces (excepting the "orthoscopic," themselves finely corrected four-lens combinations), with decidedly flat field. However, the finding of two beautiful ob-

Note: The outer surfaces of the achromatic negative lens may also be plano-concave.

jectives made by the noted Boston optician, Robert B. Tolles, has proved the advantages of this mode of magnification. These objectives are of ½ inch and ⅕ inch equivalent focus, respectively, the field of view is broad and flat, and each has a "correction collar" for compensating cover-glass thickness of microscope slides, that provides delicate adjustment of distance between the lens systems. On the writer's telescope of 60 inches focal length they yield magnifications of 120 and 300, the former easily revealing the "duplicity" of the components of Epsilon Lyrae.

Tolles, who was a contemporary of Alvan Clark, turned out the very finest of lenses, having no sympathy with "quantity production," and devoted his exceptional talent to individual perfection of workmanship. The sketch (page 194) shows the writer's method of mounting these objectives, no further description being necessary.

A good observer is "born, not made" and will logically gravitate toward the best means for each kind of observation, realizing that there is often but a small margin between failure and success, for the proper use of the telescope is a fine art. Oftentimes in the writer's long course in studying sunspots a slight raise of power has made a marked difference in this respect—such for instance as a change of ocular magnification from a 25-mm. "orthoscopic" to one of 20 mm.

Single lenses, of yet more restricted useful field than "solid" eyepieces, have some advantages in expert hands. Sir William Herschel's skill with single lenses of very high power, wrought by himself in that historic workshop at Slough, aided in the solution of the problem of getting the best out of his telescopes. When the writer was experimenting with the possibilities of single lens magnifiers—of which two that were made by the famous optician Zentmayer (of a past generation) for use with dissecting microscopes, are of superior quality—he came across some high-power single lenses by an unknown maker of many years ago. These were so mounted as to admit of combinations and were readily adapted for service with the telescope. The character of their workmanship is excellent, and the dealer who had these lenses in his stock of rarities was content to part with them for a "mere song." Even though they represent no startling advance for telescopic observation, they give opportunity for occasional trying out and would be well worth their small cost if only one observation owed success to their employment.

One must go back a hundred years to learn of the interesting experiments with small diamonds and sapphires as single lenses of high power, but which proved of uncertain optical worth, largely because of the extremely arduous task of grinding and polishing curves of faultless accuracy in such refractory substances. In some of the older books on the microscope may be found references to attempts to employ precious stones in this way, but the writer has never found any allusion to their

application to the telescope as eyepiece magnification. In Sir David Brewster's "Treatise on New Philosophical Instruments" (1813) there is an account of the attention given the possibilites of many kinds of fluids, with their indices of refraction. Later progress in the production of the finest optical glass seems to have discouraged further experiments with other materials capable of serving as lenses.

We of the present can but admire the enthusiasm that inspired the early nineteenth century investigators to perseverance in these efforts—in part at least attributable to the influence of Herschel's indomitable courage in attacking the almost impassable obstacles that stood in the path of expanding man's knowledge of the Universe. And the battle is still being fought!

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Surface Gravity and Behavior

By LAURENCE J. LAFLEUR

A question which intrigues most persons who contemplate the problem of life on other planets is that of the effect upon behavior of the difference in conditions, particularly the condition of surface gravity. It is well known, of course, that the surface gravity varies as the mass and inversely as the square of the diameter, and hence as the product of the density and diameter. To calculate the surface gravity of any planet is therefore a very simple task. It is by no means as simple, however, to appreciate what a change in surface gravity would mean to living animals. If we assume that men are somehow transported to another planet, and that either the atmosphere is adequate for their needs or that they are artificially equipped to withstand an unfavorable one, how would their muscles behave? Many of the problems involved are fairly simple ones of physics and physiology, many of them are a bit tricky in their details. All of them offer opportunities for miscalculation: so much so in fact that almost all the writers of fiction who have dealt with this subject have made serious errors. We shall therefore determine some of the basic elements of this behavior, taking the two cases of Mars and the Moon (assuming surface gravity of 1/3 and 1/6, respectively), and then present a general formula holding good for any planet and any assumption as to human characteristics.

Since we assume that the surface gravity of Mars is one-third that on Earth, a three pound object (one weighing three pounds on Earth) presses down on Mars with the same force as a one pound object on Earth. From this the incautious conclusion might be drawn that a 150-pound man who can carry 150 pounds on Earth should be able to carry 450 pounds on Mars. This, however, is only one side of the picture and 450 pounds is only a minimum value. The man himself would weigh only 50 pounds, and if he could apply the full saving to his load he could

then carry 750 pounds. This is the unattainable maximum, for the body itself is carried much more efficiently than any additional burden. For one thing its weight is better distributed; for another, part of the weight at any moment is resting directly on the ground. The actual weight that can be carried upon Mars will be a compromise between these two figures, and will tend toward the upper figure in instances where the body weight is important (*e.g.*, walking uphill), and toward the lower figure where the body weight is unimportant (*e.g.*, lifting a weight on a windlass). On the Moon, with surface gravity one-sixth of that on Earth, the load would be between 900 and 1650 pounds.

A second problem concerns throwing vertically upward a small object such as a ball. Granted the same initial velocity as on Earth, the height to which it will reach is given by the formula $D = V^2/2g$, and the height on another planet (above the point of release) will be inversely proportional to the surface gravity. On a smaller planet than Earth both the ball and the arm will be lighter, and the initial velocity slightly greater. But as the weight is insignificant compared to the power of the arm muscles, very little can be gained. On a considerably heavier planet, however, the weight of the arm and ball would be a serious consideration and the height much less than proportional to the height on Earth. If the surface gravity were sufficiently great, the object could not be lifted at all. But these considerations would not apply to the Moon and Mars. If a man, then, can throw a ball 30 feet into the air on Earth, releasing it at a height of 7 feet, on Mars he could achieve a height of somewhat more than three times 23 feet plus the same 7 feet at which the ball is released, or over 76 feet. On the Moon the height would be somewhat over 145 feet.

Consider the parallel case of how far a man can throw a ball horizontally, assuming that on the Earth he throws a ball 75 feet, releasing it 6 feet above the ground and having the ball reach a maximum height of 20 feet. The ball then rises 14 feet, which it will do in $(\sqrt{14})/4$ or .935 seconds, and falls 20 feet, which it will do in $(\sqrt{5})/2$ or 1.118 seconds. In the total time of 2.053 seconds it travels 75 feet, thus having a forward velocity (neglecting atmospheric resistance) of 36.524 feet per second. If the man throws with the same components of velocity on Mars, the ball will rise three times the vertical distance, or 42 feet, in three times the time, or 2.805 seconds. It will fall 48 feet in precisely 3 seconds, so that in 5.805 seconds it will travel a distance of 212.022 feet. On the Moon it rises 84 feet in 5.611 seconds and falls 90 feet in 5.809 seconds. So in a total of 11.42 seconds it travels 417.104 feet horizontally. As in the case of throwing vertically, these figures will be slight underestimates, and the method of calculation would be seriously wrong if applied to a surface gravity much greater than ours.

How high could a man jump on Mars or the Moon? Suppose that on Earth he jumps 3½ feet. That means that he can clear a bar 3½ feet

from the ground, but he does so in part by lifting his legs, say 1½ feet, at the top of a jump which in itself only lifts his center of gravity 2 feet. If he jumps with the same velocity, he would raise his center of gravity 6 feet on Mars or 12 feet on the Moon. Adding the height gained by lifting his legs his total jump is 7½ feet on Mars and 13½ feet on the Moon. These figures, however, are only a minimum, since a man could achieve a greater velocity in jumping against an inferior gravitational pull. A maximum may be calculated by assuming that the full power of the muscles is effectively used. If a man crouches 1½ feet in jumping, his muscular force is used through a distance of 1½ feet, and gives him a velocity which is lost to gravitation through a distance of 2 feet. The acceleration must then be $4g/3$. As this is against gravitation, the muscular force is $7g/3$. On Mars the net acceleration will be this figure minus $g/3$, or $2g$; on the Moon the amount to be subtracted will be $g/6$, giving a net acceleration of $13g/6$. These accelerations give times of $(\sqrt{3})/8$ and $(\sqrt{13})/52$ and velocities of $8\sqrt{3}$ and $4\sqrt{13}$, respectively, which will carry the center of gravity 9 feet and 19½ feet. Adding 1½ feet, the maximum jumps are 10½ and 21 feet. So on Mars the hypothetical man considered could jump somewhere between 7½ and 10½ feet; on the Moon between 13½ and 21 feet.

Consider next the horizontal jump. A man on Earth jumps, let us say, 10 feet, raising his center of gravity ½ foot during the jump and lifting his legs 1 foot before landing. He then rises ½ foot, taking $(\sqrt{2})/8$ seconds, and falls 1½ feet, taking $(\sqrt{6})/8$ seconds. In the total time of .483 seconds he jumps 10 feet, or at the rate of 20.7 feet per second. If we assume that he jumps with the same velocity on Mars, he will rise 1½ feet, taking three times as long as on earth, or $(3\sqrt{2})/8$ seconds, and then fall 2½ feet, taking $(\sqrt{30})/8$ seconds. In the total time of 1.215 seconds he will travel 25.15 feet. On the Moon the time would be $(3\sqrt{2})/4 + (\sqrt{6})/2$, or 2.285 seconds, and the distance 47.3 feet. These values are again minimum values: maximum values are to be obtained by assuming that the same force is used in each case. Notice that the horizontal component is not directly affected by gravitation in a standing jump, although the lower surface gravity of Mars or the Moon would tend to reduce this velocity by lessening the frictional grip on the ground, and that in the running jump the determining influence on the horizontal component is the speed of the run, which will also be less, as we shall show in a later paragraph. But the amount of reduction would probably be negligible, at least in the case of Mars, and we shall therefore assume that the horizontal velocity is constant for any planet. The vertical component, on the other hand, acts against gravitation, and that part of the muscular effort which is directed upwards may be treated in the same way as the simple vertical jump was treated. The amount of crouch would be less in this case than in the former; let us say 1 foot, which would give us a 3½ foot rise and a 4½ foot fall

on Mars, taking $(\sqrt{42})/8$ and $(3\sqrt{6})/8$ seconds, respectively. In the total time of 1.729 seconds the distance covered would be 35.79 feet. On the Moon the rise would be 8 feet, the fall 9 feet, the times $\sqrt{3}$ and $(3\sqrt{6})/4$, respectively, giving a total time of 3.569 seconds and a distance of 73.878 feet. Thus a man who could jump in the described manner could jump between 25.15 and 35.79 feet on Mars, and on the Moon between 47.3 and 73.878 feet.

The calculations of the previous paragraph were based upon the assumption that a man woud jump with the same vertical and horizontal components of velocity or force as upon Earth, and this assumption is probably correct for initial behavior. But if a man broad-jumps frequently he will soon hit upon the most efficient angle at which to jump, which will not be the same under different conditions of surface gravity. The actual calculation of this angle is a rather complicated one, as may be seen from the following equation. From this equation the angle ϕ can be calculated, given the surface gravity g, acceleration A acting through distance C at elevation ϕ, and additional fall (as by lifting the legs) L.

$$\frac{\sqrt{(A \sin^2\phi - g \sin\phi)}}{2A \sin\phi \cos\phi - g \cos\phi - 2A \sin\phi + 2g \sin^2\phi} + \frac{\sqrt{(AC^2 \sin\phi + CgL - C^2 g \sin\phi)}}{2AC \sin\phi \cos^2\phi - Cg \cos^2\phi - 4AC \sin^4\phi + 4gL \sin^2\phi - 4Cg \sin^3\phi} = 0$$

Although the full equation is hardly manageable, the variation from the figures produced by the method of the previous paragraph will never be great, and will practically disappear for the case of a running jump. To make the record more nearly complete we might mention that there are two factors causing the angle to vary. If a man or a projectile is given a fixed initial velocity, and falls to the same level from which it starts, the optimum angle of elevation is 45°. As the force of gravitation operates against the vertical component of the impulsion, the optimum angle is increased, and is increased less for the lower surface gravity of Mars or the Moon than it is on Earth. The effect of the additional fall is the reverse: it makes the optimum angle less than 45 degrees, and for a given fall the effect is less with lower surface gravity.

How would a man run on Mars or the Moon? The horizontal velocity of a running man is not aided or opposed by gravitation, so that as a first approximation we may suppose that running speed would be the same on any planet. Four or five modifications of this result may be considered. First, with lesser surface gravity the friction between the feet and the ground will be less. The runner will either lose efficiency by increased slippage or will have to make up for this by pressing harder against the ground, in which case he will spend more muscular force vertically, giving less horizontal speed. On psychological grounds he will be sure to do the latter, and his gait will be more of a bound than a

running step. The second effect is that the runner will remain longer in the air on each bound than he would on Earth. This means that his muscular efforts will be spaced at greater intervals, that he will tire much less rapidly, and that he will be able to keep up a sprinting pace over long distances. The third factor is atmospheric resistance. If we assume that a bound will take four times as long on Mars as on Earth, then if the Martian atmosphere is less than one-fourth the density of ours, as it probably is, the total resistance will be less and the speed somewhat higher. The fourth element to be considered is the angle the runner's body makes with the ground. This angle is so chosen that the gravitational pull presses the head forward as much as atmospheric resistance pushes it back during the period when the feet are on the ground (when in the air both effects are the same on the legs as on the head). As the density of the atmosphere falls off more rapidly than the surface gravity, the position of the runner would be more nearly upright. But in the upright position one runs less efficiently, and one would therefore run more slowly on a lighter planet! On the Moon, with no atmosphere at all, a runner would be upright except when accelerating or retarding, and would have a difficult problem to keep from falling. Balance in running is maintained in considerable part by the aid of air pressure, and in default of that a running man on the Moon's surface would require the dexterity of an acrobat. In sum, then, a man could not run as fast on a smaller planet, such as Mars, as he could on Earth, but he could run longer.

One more problem remains to be considered: how would walking be affected by a change in surface gravity? Walking, unlike the other activities we have considered, does not involve the maximum use of muscles, and the problem is very largely a psychological one. Notice first the length of stride. It is well known that a man carrying a load will walk with a shorter stride, and one may presume that if g is lessened the stride would be lengthened. But this lengthening cannot go very far because the stretching of the legs becomes uncomfortable shortly beyond the usual stride. That means that in walking against lesser surface gravity, the muscular effort must be considerably reduced. In the case of a healthy man such minimized effort is uninteresting, and such a man would probably always run instead of walking. On a planet having considerably greater surface gravity than the Earth, a reverse phenomenon would occur, and both walking and running would degenerate into crawling.

In conclusion we present the general formulae covering those of the problems susceptible of such reduction. In each case x stands for the ratio of the surface gravity on any surface to the surface gravity of Earth.

If a man weighing M pounds can carry W pounds on Earth, the number of pounds he can carry elsewhere is between

$$W/x \quad \text{and} \quad [(M+W)/x - W]$$

If a man can throw a ball H feet into the air on Earth, releasing it from a height of K feet, he can throw it elsewhere about $H - K/x + K$ feet. If x is less than 1, this figure will be slightly conservative. It is inaccurate if x is much greater than 1.

If a man can throw a ball D feet horizontally on Earth, releasing the ball at a height of K feet, and the ball reaching a height of H feet at its highest point, then the number of feet he can throw it elsewhere is

$$(D/Kx)\ [K - H + \sqrt{(H^2 - KH)} + \sqrt{(H^2 + KHx - KH)} - \sqrt{(H^2 + KHx - 2KH - K^2x + K^2)}].$$

As in the previous case this formula is conservative for a smaller surface gravity and inaccurate for a much larger one.

If a man can jump H feet upward on Earth, of which L feet result from lifting the legs, and jumps from a crouch of C feet, then elsewhere he can jump between

$$(H - L + Lx)/x \quad \text{and} \quad (H + C - Cx - L + Lx)/x \text{ feet.}$$

If a man can jump D feet horizontally on Earth, reaching a maximum height of H feet, lifting his legs L feet, and jumping from a crouch of C feet, then the number of feet he can jump elsewhere is between

$$(D/Lx)[\sqrt{(H^2 + HL)} + \sqrt{(H^2 + HL + HLx + L^2x)} - \sqrt{(H^2 + HLx - H)}]$$

and

$$(D/Lx)\ [\sqrt{(H^2 + CH - CHx + HL + CL - CLx)} + \sqrt{(H^2 + CH - CHx + HLx + HL + CL - CLx + L^2x)} - \sqrt{(H^2 + CH - CHx)} - \sqrt{(H^2 + CH - CHx + HLx)}].$$

Oxyhydrogen Combustion

A Possible Factor in Accounting for the Luminous Phenomena of Meteors

By BEN HUR WILSON

Having, for many years, carefully considered all of the various stock theories advanced by numerous authorities in texts, as well as in special books on meteoritics, attempting to account for the *Luminous Phenomena of Meteors,* I must confess that I have always had the feeling that there were certain inadequacies in their ability to explain satisfactorily the entire picture as presented in nature.

In substance, the common statement of such theories is that the friction of the meteoroid in passing so rapidly through the upper atmosphere almost instantly raises its temperature to the point of luminosity, and finally to that of fusion. Thereupon the surface becomes melted, sloughing off as luminous droplets (sparks), forming glazed coatings (often glass-like), which upon cooling are known as the exterior or

outer crust. In so far as it goes, this statement is undoubtedly correct. There are other factors, however, which should at once appear obvious to everyone giving the subject serious thought, which I do not remember ever having seen discussed in print.

It is one of these ideas, with which I have toyed for years, and which appears to me to be so reasonable that I have never been able to put it entirely aside, which I now propose to pass on, for what it is worth, as the subject of this paper. Call it a theory if you wish, as it certainly commands some supporting evidence, which I shall herewith present; or, perhaps, it is only an idea, the product of an over-imaginative mind, as has often proven to be the case with so many new suggestions for the solution of old problems.

Before proceeding with its presentation, however, there are certain phases or angles commonly connected with our currently accepted notions concerning meteors, which must be surveyed briefly, in order to obtain a more comprehensive view of the entire problem involved. Obviously, lack of space will forbid our carrying each discussion to its full conclusion, and so we shall be compelled to present only the merest outline, upon which our readers may elaborate if they so desire. They will find no dearth of literature touching upon these topics, should they feel inclined to investigate them further for themselves.

The first is the nature of friction, since this is one of the prime factors in our problem. This is the resistance to relative motion between two bodies in contact. The fundamental principles are the same, whether the bodies involved are large or small, light or heavy, moving fast or slow; are solids, liquids or gases, or any combination of such. In the case of our immediate problem, we have a relatively heavy solid (meteoroid) resisted by highly attenuated gases, the upper atmosphere, through which it is rapidly passing.

Between solids, friction seems to be due to the interlocking of minute roughnesses upon their surfaces, with the clinging (cohesion) together of the points of closest contact. By retardation, or loss of momentum, energy is dissipated by being transformed into heat, which is lost through radiation. With a solid passing rapidly through gases, the resistance, it is evident, is due to the high pressure created in front of the moving object in the clearing of its path of gaseous molecules for permitting its passage since, of course, both are unable to occupy the same space at the same time.

In the case of bodies traveling at the maximum speed of meteorites (usually stated to be at from 30 to 50 miles per second), the pressure, even in the rarest of gases, becomes enormous and the amount of retardation by the cushioning effect of the compressed gases of the atmosphere is considerable. Herschel estimated this pressure to be a little over 10,000 pounds per square inch, for meteoroids at an altitude of twelve miles and traveling at a rate of twenty-seven miles per second. The net

result, attending this loss of momentum, is nevertheless the same in all cases, whether it be the melting of a lead bullet striking a stone wall, or the heating of a meteoroid to incandescence in the Earth's upper atmosphere; *i.e.*, the transformation of energy through the generation of heat and its dissipation through radiation.

All of the factors bearing upon the problem of the quantity and the intensity of the heat so produced, being dependent upon such items as the initial and end velocity of the meteoroid itself; its initial and final temperature; its mass; its substance; its latent heat; the density, nature, and temperature of the resistant gas; and the extent of radiation, are measurable and their effects, both singly and collectively, are reducible to formulae. Nininger states that under optimum conditions, temperatures around 7,000° F. may be developed at a height of 70 miles (117 km.) or more above the Earth's surface.

The individual mass of the vast majority of these objects, it is stated, is surprisingly small, ranging in size from only a few molecules to that of marbles, most of them probably being no larger than pinheads. The entire substance of all of these smaller ones, it is evident, is wholly consumed or disintegrated in their swift passage thru the upper atmosphere, their solid residue finally reaching the Earth's surface in the form of minute particles or dust, while their gaseous molecules and free atoms are incorporated into and become a part of the great mass of the atmosphere. Remnants of the larger ones only, come crashing on down into the lower atmosphere sometimes falling to the Earth's surface as meteorites. These may vary in weight from a few ounces to many tons. Those of the greatest size, forming craters, are exceedingly rare. The average weight of all meteorites may, perhaps, be only a few pounds or even less.

It has been explained, by some authors, that the sparks of the meteor train are the result of the gas molecules of the upper atmosphere colliding with and knocking off other molecules from the surface of the meteoroid, in the form of luminous particles not unlike those coming from a stone which is held firmly against a grinding or emery wheel. To me, it seems impossible to think of this analogy as being literally true, or that the percussion of any molecules, however large and massive they might be, or at whatever speed they might be traveling, should be able to dislodge incandescent particles which would be visible at distances of from 50 to 70 miles, as would be necessary in the case in question. This is particularly true in view of the fact that the elevation at which the phenomena of meteoric luminosity take place only atoms of the very lightest gases, hydrogen and helium, prevail and that these are there present only in very rare or attenuated quantities. Knowing that one must employ a lens to detect this same type of phenomena, when using the Crooke's spintheriscope for viewing the alpha particles dislodged by radium bombardment as seen from a distance of only a few millimeters

from the eye, makes this percussion theory appear all the more untenable.

Another item, to which we should give very careful consideration before proceeding with the statement of our theory, is the physical nature of the so-called meteoric "train" or "smoke cloud," which accompanies those bodies which approach the magnitude of "fire-balls." Many times these have been beautifully and precisely described by competent, critical observers. The matter with which we are particularly concerned is their volume and constituency. The course of many such meteors has been observed and followed across the country several hundred miles. The diameter of the "smoke cloud," which has often been visible at elevations of from 30 to 50 miles, and at from even greater distances when viewed obliquely, must have been not less than a thousand feet, which would imply that the total volume, of the residual dust, gas, or "smoke" so generated may have been several cubic miles. This estimate has been so stated by several authorities. I very seriously question whether this result could be obtained by any simple process of fusion or disintegration of the meteoroidal substance caused solely by the agency of the friction of the atmospheric gases involved, or by any other means so simple. This, of course, immediately raises the question as to how else this phenomenon might be accomplished.

Elementally, the composition of meteorites is substantially the same as that of the Earth. Indeed, the planetesimal theory of Chamberlain and Moulton postulates an Earth made up of an aggregate of meteoroidal material which has been slowly accumulated from space, about a central nucleus, throughout long eons of time. There is no good reason for believing that the average substance of meteorites now falling is very different from that which fell during that great period of "ingathering," in which the present Earth was built. The percentage composition of the material composing the Earth's outer crust has been carefully calculated and well established for many years. Such eminent authorities as Clarke and Farrington have likewise estimated the percentage composition of known meteorites and, comparing it with that of the Earth, found surprisingly close correlation. Their estimates for the Earth show oxygen, free and combined, making up nearly one-half (47.17%) of its entire substance, and for meteorites even a slightly greater percentage. I make this point, since oxygen is a very active element, being the principal supporter of most forms of combustion.

This brings us to a brief consideration of the nature of combustion, a matter which seems so common that not much need be said about it. Commonly speaking this phenomenon is usually considered to be the rapid oxidation of some substance, more often carbon, with which it will readily unite. This process may be slow, as that taking place within our bodies, or rapid as in the case of an explosion or where intense heat is generated under forced draft. In case the resultant chemical

reaction is such as to create a molecular disturbance within the ether, waves are thrown off which we recognize as light. Many other elements, under proper conditions, involving such matters as concentrations, pressures and temperatures, will also unite with oxygen with similar physical results. In the laboratory, and occasionally in nature, iodine, chlorine, and some other substances perform the same function as oxygen, producing incandescence. The most perfect combustion takes place between the elements hydrogen and oxygen, a fact upon which we shall elaborate later. It is a singular circumstance that compression renders the combusion of gases less perfect, and, within certain limits at least, the more rarefied the atmosphere in which a flame burns or reaction occurs, the more complete and perfect is its performance. This is a matter of great significance which we must not lose sight of.

For some substances initial combustion takes place spontaneously, but for the most the temperature must first be artificially raised to the kindling point, which varies greatly according to the nature of their affinities. For example, phosphorus will kindle at ordinary room temperature, while sulphur and carbon require higher, though not excessive, temperatures. This kindling or initial reaction temperature is also a very important factor in our problem. Luminescence (the condition under which light waves are given off) occurs at lower temperatures for some substances than for others. Thorium and calcium oxide, for instance, become "white hot" at moderate temperature, while other substances require a much greater heat to produce similar results. The molecules of many compounds are stable at ordinary temperatures, while all are known to break down or dissociate into their component elements if the temperature be raised sufficiently high. Few, if any compounds can exist, as such, at temperatures above 5000° F. and, as has been shown by magmatic studies and experimentally, even some silicates will at least partially dissociate at much lower temperatures.

The original source of the Earth's atmosphere is a matter which is subject to much conjecture. It is believed by many, to be a residual product of the cooling primeval body, while others suggest that it has been acquired, in the past and is being maintained at the present time by the accretion of disintegrating meteoric material. It was Chamberlin's belief, that should the Earth ever be deprived of its atmosphere by cosmic accident, a new one substantially the same as the old, would be reacquired by meteoric means, in the course of a few hundred million years. This would then imply that, in addition to their solid substance, meteoroids must also carry a considerable amount of entrapped or occluded gases, which in fact many observations have shown to be true, even after they have reached the Earth's surface. Doubtless they carried much more free gas while flying through the cold of outer space than most of us realize, much of which would be lost soon after their entering the Earth's upper atmosphere, being driven out of or off

by the great increase in temperature. To be able to reconstruct an atmosphere, at least similar to our present one, would imply that they must have occluded within them the same elements of which our atmosphere is now composed. This would include such gases as nitrogen, oxygen, argon, hydrogen, helium, in quantities, and some other rarer gases in lesser amounts.

The individual gases of the atmosphere exist together only as a mixture; that is, they are in a free or uncombined state. This leaves them power to move about at will under the influence of gravity, the heavier ones, such as carbon dioxide, oxygen, nitrogen, and argon, segregating themselves in the lower, while the lighter ones, such as hydrogen and helium, push upward into the upper levels. This implies that composition of the atmosphere changes gradually with altitude, and so in fact at one level it may not even resemble that of another. Atmospheric pressure also changes with altitude, it being due to the sustaining weight of the total air column, and so at the higher altitudes this pressure becomes almost negligible, approaching zero, and the gases there present are consequently greatly rarefied or attenuated; all of which has important bearing upon our problem. Since we are now interested only in the zone of meteoric luminescence (the moderately high altitudes) let us examine the following table of percentages, and see what we may find.

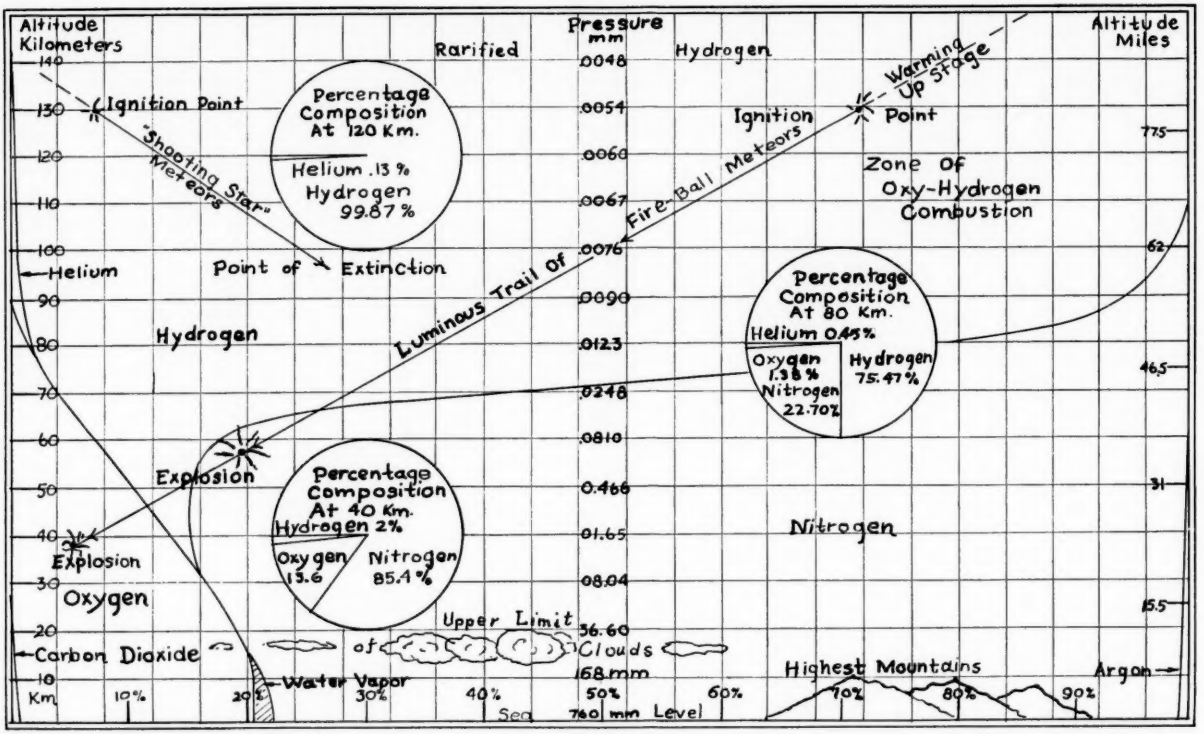
PERCENTAGE COMPOSITION OF THE ATMOSPHERE AT VARIOUS ELEVATIONS*

Ht. in Km.	H	He	CO_2	Ar	O	N	Ht. in Miles
150	99.73	0.27	0.00	0.00	0.00	0.00	93.0
100	97.84	0.46	0.00	0.00	0.07	1.63	62.0
80	75.47	0.45	0.00	0.00	1.38	22.70	49.6
50	3.72	0.03	0.00	0.08	10.01	86.16	31.0
30	0.20	0.00	0.00	0.22	15.10	84.48	18.6
15	0.02	0.00	0.02	0.74	19.66	79.56	9.3
5	0.01	0.00	0.03	0.94	20.95	77.89	3.1

*After Humphrey's *Mount Weather Bulletin*, Vol. 2, p. 66, 1909.

The usual procedure in giving the varying composition of the atmosphere is to operate from the bottom upward. However, in the present instance, it seems to suit our purpose better to reverse this order, since we are concerned more with its uppermost layers. From the above table it will be noted that at an altitude of 93 miles more than 99.73% of the atmosphere is hydrogen, which amount decreases to 97.84% at 62 miles above the Earth's surface, and to 75.47% at 49.6 miles. In other words, at the elevation at which the phenomenon of luminosity of meteors takes place, hydrogen is practically the sole occupant of space. With this and the previously stated facts in view, let us now proceed with a narrative of what we believe actually happens.

Meteoroids, coming down through the ceiling of our atmosphere, from outer space, carrying with them in addition to their own solid substance a considerable amount of entrapped or occluded gases, including



Note: For **Rarified** please read **Rarefied.**

FIGURE 1

PERCENTAGE COMPOSITION OF THE ATMOSPHERE AT VARIOUS ALTITUDES ABOVE SEA LEVEL.

oxygen (though its quantity is not thought to be as great as some other gases so carried), traveling at enormous speed, meet the ever increasing resistance of this hydrogen gas. Due to friction and the frontal pressure built up ahead of the flying meteoroid, marked retardation soon occurs and the energy lost by the decreased momentum is quickly transformed into heat, which spectroscopic observations indicate may range as high as 7,000° F. This is much higher than is needed to produce incandescence and fusion, and causes the actual ignition of any such occluded oxygen, as might have been carried by the meteoroid into the atmosphere, with the terrestrial hydrogen gas by which it is immediately surrounded.

Inasmuch as this oxyhydrogen combustion is the hottest chemically produced flame known to man, it not only sustains the original high temperature as the meteor (as it is now called) is being gradually slowed down while passing through the atmosphere, but its great heat also brings about a certain amount of atomic dissociation of the meteoric substance itself (composed largely of oxides and silicates), which in turn thereby continues to release sufficient free oxygen to maintain the reaction. All goes well until an altitude of about 50 miles is reached, below which the composition of the atmosphere rapidly changes from a preponderance of the highly combustible hydrogen to that of the more inert and non-combustible nitrogen. Here a rapid cooling takes place, since the required percentage of hydrogen is no longer present to support the combustion, while at the same time the quantity of the inert nitrogen becomes sufficient to quickly extinquish it. (See Table and Fig. 1.) Here also the pressure of the atmosphere rapidly increases and an altitude zone is reached where there is a marked decrease in temperature from that immediately above it. All of these factors can only operate to place the meteoroid under terrific stress, sufficient in many cases to rend it quickly asunder with explosive force, and with consequent detonations and shattering.

Some may seriously question the ability of hydrogen in so highly attenuated a state, as it must exist in at this great altitude (.0098 mm atmospheric pressure at 140 km.), to support the vigorous combustion indicated by the visible phenomena of the flaming meteor. All who are familiar with the torch bearer swinging or running with his torch through the air, to enliven the flame by increasing the normal supply of oxygen, must realize that the onrushing meteoroid must in the same manner increase its supply of available hydrogen, even to a greater extent by reason of its much greater speed. Should the zone of combustion (oxidation) of the surrounding hydrogen extend outward from the surface of the white-hot meteoroid for a distance of only half an inch, and which is certainly a reasonable assumption, and its speed be as much as 50 miles per second, then the amount of hydrogen pouring past the surface and coming under the immediate influence of its com-

FIGURE 1
PERCENTAGE COMPOSITION OF THE ATMOSPHERE AT VARIOUS ALTITUDES ABOVE SEA LEVEL.

Note: For **Rarified** please read **Rarefied.**

bustion would be 6,336,000 times as much ($2 \times 12 \times 5, 280 \times 50$) per second as if the object were standing absolutely still. This amount, it would seem, would certainly be more than enough to meet all ordinary requirements and to satisfy well every contingency of the premise.

Let us now look to the matter of the by-product of this oxyhydrogen combustion. Every school boy knows that one atom of oxygen combines with two atoms of hydrogen to form one molecule of H_2O,—or water

FIGURE 2

Meteoric "train" resembling steam-cloud. Photo by Monnig. (Published with permission from Wylie's, "Astronomy, Maps, and Weather." p. 371.)

vapor. At the intense cold of the upper atmosphere this would instantly condense and become frozen into ice particles or clouds. Picking up these two additional atoms from the atmosphere would thereby increase the extent of the gas volume liberated from the flaming meteor by some three fold. How many times in the literature have we read of the meteor "train" resembling a cloud of steam. It has often been described as, "the course of a locomotive traveling rapidly under full

steam, on a cold day." Should one take the trouble to examine carefully Mr. Monnig's photograph, on page 371 of Wylie's recent work, "Astronomy, Maps, and Weather," (Fig. 2), he cannot help but be impressed with the marked resemblance of the meteor "train" to ordinary cloud formations. In no other manner can I conceive of such enormous clouds being formed out of so little material as these meteoroids must contain. Most other gases conceivably present would more than likely be of invisible material, since the elements required for forming a visible "smoke" are not present in sufficient quantities to meet the requirement.

In the foregoing I have attempted briefly to place before you an outline of all of the more pertinent evidence required to evaluate the theory that oxyhydrogen combustion is, at least in part, responsible for the luminous phenomena of meteors and their attendant "smoke train." I feel that each point made will bear up under further critical examination of the literature, and, by way of conclusion, allow me now to present the following summarization:

(1) Approximately one-half of the substance of meteoroids entering the Earth's atmosphere is composed of oxygen, chemically combined with other elements in the form of oxides and silicates, and in addition some free oxygen carried as occluded gas is also present. (2) These meteoroids traveling at high speed are definitely resisted by the gases of the upper atmosphere, and their speed being thereby greatly retarded by the direct impact, frontal pressure, and/or friction of the gases present the energy loss in momentum is quickly transformed into heat, which soon reaches the very high temperature, variously estimated to be around 7,000° F. (3) At this temperature volatilization of the oxygenous minerals takes place and the free and freed oxygen present rising above the required kindling temperature of 700° C. (about 1400° F.), instantly unites with the hydrogen gas, of which the upper atmosphere is almost entirely composed. (4) The intense heat of this reaction, it being naturally the hottest chemical flame known to man, is augmented by: (a) the rarefied condition of the gases present at this altitude, which make for more perfect combustion; (b) by a certain amount of atomic hydrogen present along with the molecular; and, (c) by the torch-like effect of the rapidly moving meteoroid, which brings an abundant supply of hydrogen into contact. (5) At this high temperature molecular disintegration of compounds takes place, and they dissociate into their free component elements, thereby releasing sufficient free oxygen to maintain the phenomena. (6) Spectroscopic analysis of meteoric light shows plainly the presence of the luminous white-hot gases of hydrogen and helium, as it should be under these circumstances. (7) Meteoroids do not usually carry the proper elements of ordinary combustion to produce either the type or volume of the so-called "smoke-train" as observed in the visible phenomena. (8) Neither would they be able to produce by the mere process of friction and/or

fusion the quantity of luminosity exhibited by the meteoric flame. (9) The mass of the average meteoroid is insufficient to furnish the volume of the material required to account for the "smoke-train" phenomena as witnessed. (10) The by-product of oxyhydrogen combustion is water vapor, which at the temperature of the upper atmosphere quickly condenses and freezes to form the cloud-like trains which have so many times been described and occasionally photographed.

In view of the above, *Oxyhydrogen Combustion as a Factor in Accounting for the Luminosity of Meteors* seems to be a rational, as well as a satisfying assumption, and one which I trust will furnish my readers a new line of thought for their careful consideration.

JOLIET ASTRONOMICAL SOCIETY, JOLIET, ILLINOIS.

The Planets in May, 1943

By ALICE H. FARNSWORTH

NOTE: Greenwich Civil Time is used unless otherwise stated. To obtain Eastern Standard Time subtract 5 hours; Central Standard Time, 6 hours, etc. War Time in each zone is one hour later than Standard. Phenomena are described as seen from latitude 45° N. *The American Ephemeris and Nautical Almanac* is the source of most of the data.

Sun. The Sun moves from its position in the constellation Aries (α 2^h 29^m.4, δ +14° 44'.3 on May 1) into Taurus (α 4^h 31^m.9, δ +21° 54'.0 on June 1). From Manila, Hyderabad, Lake Chad, the Cape Verde Islands, Martinique, and Honduras at the beginning of the month the terrestrial sub-solar points move north to Hongkong, Mandalay, Mecca, Mexico City, and Honolulu.

Moon. Phenomena are as follows:

		h	m
New Moon	May	4	9 43
First Quarter		12	9 52
Full Moon		19	21 13
Last Quarter		26	13 33
Runs high		8	21
In apogee		10	17
In perigee		22	14
Runs low		22	17

The waxing crescent passes four planets in three days (May 5 to 7). Occultations are few. Westerly longitudes see Regulus occulted on May 12-13. This night or the next would be best for examining Plato with a high power to see whether you note the "harvest" effect mentioned by Mr. Barker (POPULAR ASTRONOMY, **48**, 19, 1940).

Mercury moves first eastward then westward in Taurus, passing Uranus on each branch of the loop (May 5 and 18) on its way to inferior conjunction with the Sun on May 23.

Venus, conspicuous evening star, grows gradually brighter to the eye while its waning gibbous disk in the telescope grows larger in apparent diameter. It forms a brilliant pair with Jupiter to which it draws ever closer during the month.

Mars swings along from Aquarius into Pisces, rising more than two hours before the Sun. It now appears slightly brighter than Antares, its rival in ruddy color, visible at an equal altitude in the southwest an hour before sunrise, as May opens.

Jupiter moves eastward in Gemini, rapidly approached by Venus from the west. The Moon, passing 6° south of Venus on May 7, reaches Jupiter two days later. It is of interest to note that in the following lunation these conjunctions will occur only ten hours apart and in reversed order.

Saturn may still be seen after sunset at a low altitude in the west in the early part of the month. It is now clearly east of the Hyades. By the end of May it will be very close to the Sun.

Uranus comes to conjunction with the Sun on May 26.

Neptune, still moving very slowly westward in Virgo, is well placed for telescopic identification. Its position on May 15 ($\alpha\ 12^h\ 0^m$, $\delta + 1°.5$) will serve for finding purposes throughout the month.

The physical characteristics of Jupiter make it a most reliable and satisfactory object for exhibit in the telescope on visitors' nights at the observatory, or for private study. Great interest centers in the phenomena of its ever-circling four bright moons. The planet itself is so bright that haze or thin cloud often serve only to improve the view by increasing the steadiness of the seeing. Its dark belts are so prominent that any eye will detect them readily, and its amazing rapidity of rotation (once around in less than 10 hours) can be demonstrated in a very short time if a convenient spot or irregularity in a belt is present. Indeed one can view the entire surface of the planet by examing it at 7:00 o'clock in the evening and again at midnight.

Starting on a hunt for the famous Red Spot, visible as an oval marking or depression in the broad belt south of (above in the telescope) the planet's equator, one could wonder why almanacs do not regularly provide its longitude. One sufficient reason might be that it does not remain anchored in longitude; almanacs published far in advance confine themselves to comfortably predictable data. The admirable 30th Report of the Section for the Observation of Jupiter, published in the *Memoirs of the British Astronomical Association* (Vol. 34, Part 3), covers Jupiter's apparitions in 1934, 1935, and 1936; gives detailed descriptions of the appearance and behavior of varied surface markings; and reproduces many drawings made with telescopes varying from 6 to 18 inches in aperture.

The appended table of longitudes of the Red Spot over a period of years indicates its erratic behavior. The data, taken largely from the above Report and earlier ones, are supplemented, as indicated, by information from observers of Jupiter in this country. The main tendency shown here is a progressive decrease in longitude by non-uniform amounts. It was our hope to report at this time its present appearance and longitude, but examination of the planet with the 8-inch refractor in a variety of Jovian longitudes between February 27 and March 14 failed to reveal it. Perhaps some one who reads this article will report better success. As a guide to designating the position of the Red Spot, the following facts will be useful:

> The longitude of Jupiter's central meridian (on System II, appropriate to the latitude of the Red Spot) on April 15 at 0^h G.C.T. is 88°.6.
>
> This longitude of the center increases steadily with time, 36°.26 per hour, 870°.27 per day.

Longitudes of objects on the visible surface relative to each other increase from west to east (left to right in the telescope) in a direction opposite to that of the planet's rotation.

Thus the estimated angular distance of a marking to the east (right) of the planet's central meridian should be added to the momentary longitude of the center.

LONGITUDE OF THE RED SPOT

Year	λ_2	Year	λ_2
1922	256°	1934	180
1923	230	1935	158
1924	172	1936	142
1925	90	1937*	139
1926	21	1938 June†	140
1928	315	Sept.†	150
1932*	228		

*Latimer J. Wilson, *Sky*, January, 1938, p. 10.
†Hugh M. Johnson, *Sky*, June, 1939, p. 14.

In spite of the fact that Marius and Galileo began collecting information about Jupiter 3⅓ centuries ago, the planet continues to make the astronomical headlines fairly often.

The first addition to the four bright Galilean satellites came after an interval of nearly 300 years. The 5th satellite, circling close to Jupiter, was promptly found by the skillful and assiduous young observer, E. E. Barnard, after less than a dozen nights of work with the great Lick refractor. For the second issue of POPULAR ASTRONOMY (October, 1893) published one year after the discovery, Barnard wrote an anniversary summary of current knowledge of the new satellite.

Then came the era of discovery of moons of Jupiter by photography, Perrine at Lick, Melotte at Greenwich, and Nicholson at Lick contributing four discoveries of far fainter, more distant satellites in the decade 1904 to 1914. In the summer of 1938 Nicholson's search with the most powerful instrument yet used for the purpose, *viz.*, the 100-inch reflector at Mount Wilson, yielded two more moons, fainter and tinier than their predecessors. So we now recognize a group of three (Satellites VI, VII, and X) at a distance of seven million miles from Jupiter, and another group of three (Satellites VIII, IX, and XI) twice as far away from the planet.

About ten years ago, notably through the work of Wildt at Göttingen and Dunham at Mount Wilson came the answer to the long puzzling question of the origin of the heavy absorption bands introduced into the spectrum of sunlight by its penetration into the atmospheres of the giant planets. These bands, well shown in Slipher's photographs of planetary spectra, were stronger in the colder, more distant bodies. On Jupiter the presence of ammonia (NH_3) and methane (CH_4) in amounts proportional respectively to depths of 10 meters and to half a mile by terrestrial atmospheric standards stood revealed. Both of these are hydrogen compounds. With water (H_2O), they are the combinations logically to be expected at the surface of a very massive body like Jupiter, which during its process of cooling would have retained in abundance even so light a gas as hydrogen.

At Jupiter's sub-frigid temperature (216° below zero F.) the water is undoubtedly frozen, far below the visible surface, possibly in a deep layer of ice extending to within less than half a radius of the center of the planet. Ammonia must also be largely present as ice crystals in Jupiter's visible clouds, enough being present in gaseous form to lessen the solar radiation slightly. Methane

survives in gaseous form at even a lower temperature than that of Jupiter and produces the heaviest absorptions in the spectrum of Jupiter and the other giant planets.

Assuming that no appreciable amount of heat from radioactive or other sources is being successfully distributed from within the planet, Jupiter may reasonably be regarded as possessing a heavy metallic core (about 38 thousand miles in diameter), surrounded by the deep layer of ice (possibly 17 thousand miles thick) which underlies the outer shell (8 thousand miles deep) of ammonia and methane. This last, gaseous at upper levels, may under the heavy pressure of its own weight become practically liquid down below. These proportions of heavy and light materials would represent the known low average density (1.34 times water) of the planet. The true nature of a huge, persistent, unanchored surface-marking like the Red Spot, which may be supposed to be as deep as it is wide, and its relation to the model just described are problems whose solutions will in the future put Jupiter again into the headlines.

Valuable articles to which the writer is indebted and to which the reader is referred for more information are

Dunham, Theodore, Jr., "Knowledge of the Planets in 1938," *Pub. A.S.P.*, **51**, 253, 1939.

Nicholson, S. B., "The Satellites of Jupiter," *Pub. A.S.P.*, **51**, 85, 1939.

Wildt, Rupert, "The Constitution of the Planets," *Proc. Amer. Phil. Soc.* **81**, 135, 1939.

Asteroid Notes

By HUGH S. RICE

Several of the minor planets are in a position for observation with small telescopes during the next few months. However, the brightest ones are not observable until later.

The first one available is planet 3 Juno, which comes to opposition on July 13. It is rather faint for small telescopes at the present time, the photographic magnitude being computed as approximately 11.5 for the first of May; but it brightens to 10.3 in July. Juno has the faintest average magnitude at opposition, of any of the Big Four of the asteroids. This planet is in southern Aquila in April. The accompanying ephemeris was computed by Dr. Paul Herget of the *Nautical Almanac* Office.

ASTEROID EPHEMERIDES. FOR 0^h U.T. EQUINOX OF 1943.0

	3 Juno			7 Iris		
		α	δ		α	δ
		h m	° ′		h m	° ′
Apr.	11	19 35.8	−8 26	Apr. 16	21 7.9	−13 32
	16	19 39.3	−8 1	21	21 14.9	−12 51
	21	19 42.5	−7 36	26	21 21.6	−12 9
	26	19 45.2	−7 12	May 1	21 28.1	−11 27
May	1	19 47.5	−6 48	6	21 34.3	−10 45
	6	19 49.3	−6 24	11	21 40.2	−10 2
	11	19 50.7	−6 1	16	21 45.8	− 9 20
	16	19 51.6	−5 40	21	21 51.1	− 8 38
	21	19 52.0	−5 20	26	21 56.1	− 7 56
	26	19 51.8	−5 2	31	22 0.7	− 7 16
	31	19 51.0	−4 46	June 5	22 4.8	− 6 36
June	5	19 49.7	−4 33	10	22 8.6	− 5 57
	10	19 47.8	−4 23	15	22 11.8	− 5 20

The second asteroid available is 7 Iris, and the opposition date at this apparition is August 20. It is brighter than Juno, the photographic magnitude being computed at 11 for the first of May, and brightening to 10 at the end of June. At opposition time it is considerably brighter yet, being 8.6. Hence it should be within the range of high-power binoculars all summer. This planet is near the Capricornus-Aquarius boundary on the first of May. The accompanying ephemeris was computed at the Yale University Observatory and is included here by courtesy of Dr. Dirk Brouwer.

Other notes, positions, and probably charts, on the best asteroids to observe, will be given in this department.

Hayden Planetarium, American Museum of Natural History,
New York, New York, March 22, 1943.

Occultation Predictions for May, 1943

(Taken from the *American Ephemeris*)

Date 1943	Star	Mag.	IMMERSION Greenwich C.T.	*a*	*b*	Angle E from N	EMERSION Greenwich C.T.	*a*	*b*	Angle E from N
			h m	m	m	°	h m	m	m	°
Occultations Visible in Longitude +72° 30′, Latitude +42° 30′										
May 10	d^2 Cnc	6.2	23 40.6	..	..	174	0 13.2	..	..	219
11	π Cnc	5.6	23 21.5	—1.6	—2.1	133	0 42.3	—2.0	—0.9	268
17	65 Vir	5.9	3 26.6	—1.5	—1.4	128	4 44.1	—1.6	—1.4	286
17	66 Vir	5.8	4 28.1	—1.1	—2.1	145	5 33.3	—1.5	—1.2	265
22	15 Sgr	5.4	5 44.8	—1.6	0.0	116	6 57.1	—1.9	+0.4	254
22	16 Sgr	6.0	5 57.4	..	..	34	6 36.0	..	..	336
24	σ Cap	5.5	5 32.5	—0.8	+0.4	122	6 28.5	—1.5	+1.9	228
26	42 Aqr	5.6	5 59.8	—0.4	+1.2	101	6 58.1	—0.9	+1.9	231
Occultations Visible in Longitude +91° 0′, Latitude +40° 0′										
May 13	α Leo	1.3	2 22.0	..	..	55	3 3.6	..	..	356
16	γ Vir	2.9	8 38.8	—0.2	—2.8	160	.. ..	..	..	...
17	65 Vir	5.9	3 8.0	—0.8	—2.3	163	4 8.1	—2.7	+0.4	256
17	66 Vir	5.8	4 21.1	..	..	186	4 53.1	..	..	232
22	16 Sgr	6.0	5 15.3	—1.6	+1.8	65	6 15.0	—1.1	—0.3	312
22	15 Sgr	5.4	5 24.8	—0.6	—0.4	141	6 18.0	—2.0	+1.7	236
22	21 Sgr	5.0	10 46.4	—1.3	—0.3	68	11 54.1	—1.2	—1.5	283
24	σ Cap	5.5	5 28.7	+0.5	—1.4	152	5 54.8	—1.6	+3.8	202
24	o Cap	6.1	10 45.1	—2.0	—0.2	91	12 0.5	—1.4	+0.2	238
Occultations Visible in Longitude +120° 0′, Latitude +36° 0′										
May 10	g Gem	5.0	4 43.0	—0.8	—1.1	90	5 48.3	—0.1	—1.9	298
13	α Leo	1.3	1 4.8	—2.1	—0.2	111	2 37.9	—2.2	—1.1	295
14	χ Leo	4.7	7 49.8	—0.7	—1.5	105	8 54.3	—0.2	—1.9	301
16	BD—0°2603	6.1	9 34.5	—0.4	—3.0	162	10 15.8	—0.5	—0.4	243
22	21 Sgr	5.0	9 51.8	—2.2	+0.8	69	11 8.5	—2.1	—0.9	294
24	o Cap	6.1	9 48.1	—1.6	+0.9	92	11 5.4	—1.9	+1.0	251
29	26 Cet	6.2	10 43.5	0.0	+1.3	84	11 40.5	—0.3	+1.9	233

The quantities in the columns *a* and *b* are given for the purpose of making these predictions useful for any place within 200 miles of the point indicated. The procedure is as follows: Subtract the longitude of the point given from the longitude of the place in question; multiply the result in degrees, taking the signs into account, by the quantity under *a* for the star to be observed; similarly,

with the latitude, using b; apply the sum of the products, with its proper sign, to the Greenwich C.T., and obtain the predicted Greenwich Civil Time for the phenomenon at the place of observation. To obtain Eastern Standard Time it is necessary to subtract five hours; Central Standard Time, six hours, etc.

METEORS AND METEORITES

Meteor Notes from the American Meteor Society

By CHARLES P. OLIVIER, President

One of the purposes of these notes is to bring to the attention of meteor observers important articles published on the subject which, for one reason or another, may not be readily available to persons most interested. However, the number of such articles has increased so greatly in the past dozen or more years that this has become impracticable except very occasionally. Further the proper analysis of such articles would take more time than the writer frequently has to spare, and also current A.M.S. work must not be neglected.

In Vol. II, *Annals of the Tadjik Astronomical Oservatory*, dated 1941 but just received here, there are two long articles of outstanding importance and interest, both most fortunately with an excellent English summary. The first is "Results of Observations of Meteor Trains in Tadjikistan (1934-1938)" by V. V. Fedynsky, 38 pages with an 8-page summary; the second, "Telescopical Meteors in the Years 1937-39" by A. M. Bakharev, 41 pages with a 2-page summary. As there are long tables in each, which the authors have made quite intelligible despite an inability to read Russian, the essentials of both studies are within reach. It is sincerely to be hoped that other authors, writing in languages which most of us cannot read, will follow increasingly these good examples.

As to the first paper, out of 41 long-enduring meteor trains observed according to a regular program, 37 were recorded by N. I. Guriev and 4 by the author himself. A comet-finder of 162 mm. aperture, field of 150′, was used for 32 trains, and a 175 mm. refractor, field of 52′, was used for 8 trains. The series was therefore very uniform. A two-page table gives the fullest data on each train and its direction of drift. For the linear velocities, a "constant height of the trains was adopted . . . H = 83 km. being the moda of the asymmetrical distribution of the observed values according to a summary of Trowbridge (*Ap. J.* **26**, 95, 1907)." Others have, I believe, generally preferred 90 km. as an assumed mean. My own value, calculated in *F. O. Reprint* No. 60, is 88 km. Numerous other tables and vector diagrams aid in interpreting Fedynsky's conclusions. Incidentally, *F. O. Reprint* No. 60 was published too late to be used in the author's discussion, and apparently he had not seen the earlier Reprints No. 18 and No. 29 where several trains observed in this country were fully discussed.

Perhaps the best way of showing the general results is to quote his Conclusions:

> "(1) The present work was performed on the base of 41 observations of noctilucent meteor trains, obtained at the Tadjik Astronomical observatory in 1934-1938. (2) The materials of observations are listed in a catalogue of meteor trains, accompanied in the text by the necessary explanations. (3) The shape of meteor trains shows that in 60% of cases there are considerable differences in velocity and direction of the drift, which in its turn bears witness of the existence of distorted air currents

of different velocity in the upper atmosphere, *i.e.*, of the latter's turbulent motion. (4) The position and motion of trains was studied on the premise of the constancy of their average height (H = 83 km) and the absence of vertical displacements, which is a statistically correct supposition. (5) 39 meteor trains were observed above the Tadjik, Uzbek, Hazakh Socialist Republics and above the Afghanistan, from 30° to 40° north latitude. (6) The general picture of the motion of trains resembles very much the results obtained earlier by Trowbridge (1907) and Kahlke (1921) for Western Europe and North America: directions towards the East prevail; most frequently velocities of the order of 70 m/sec are met with. (7) The motions of trains are more intensive before midnight (velocities of 20 to 350 m/sec predominate) and their directions are disorderly. South-west directions are recorded in the evening. After midnight there appears a strong predominance of eastern directions and a general decrease of velocity of the train drift. (8) The diameter of the trains is of the order of several hundreds of meters at the time of their rise, which is in complete agreement with the foregoing data and depends on the absolute brightness of the meteor. This interrelation is satisfactorily accounted for by the theory of phosphorescence (after glow) of trains. (9) The velocity of diffusion is, according to the observations, a magnitude of about 7 m/sec, which is the lower limit for the value of velocity in view of the fact that the effect of fading of the train about the edges has not been taken into consideration. In fact the velocity of diffusion of trains ought to amount to tens of m/sec. (10) The material collected permits to make some suppositions on the character of the circulation of the upper atmosphere. With the stationary motion of aerial masses in the upper atmosphere there ought to exist barical gradients of the order of 10^{-3} mbars per 100 km. Going with the general magnitude of pressure of several hundred of millibars at these heights, this is a great magnitude, which cannot hold out on a considerable distance. Therefore the motion of the upper atmosphere ought to be of a complicated character, determined by the existence of a definite number of centers and zones of extreme pressure. (11) The materials at hand are insufficient for a more or less detailed analysis; they allow, nevertheless, to establish on the base of observations of motion of meteor trains, of aurora borealis, of night luminous and iridescent clouds the presence of independent circulation in the upper atmosphere resembling the system of trade-winds and anti-trade-winds of the troposphere. This circulation complicated by local influences is proved for aerial masses at heights of 30-100 km, its existence is very probably still higher, The main boundary of the division of drifting air masses is the layer at the height of 82-85 km. According to data of the study of spectra of aurora borealis and of the motion of meteors, a quick increase of temperature with the height is observed here, which is accounting for the impeding action of this layer."

In view of the above, and using his numbering, (3) is a well-known fact, but no reference is seen to his having found definite vertical components as I did for trains No. 1087 and 1088, *F. O. R.* No. 60. As to (6) and (7), frankly the data in *F. O. R.* No. 60 have never been fully analyzed, but the partial analysis that was made did not, in general, confirm the conclusions of Kahlke. With these new Russian data a full analysis of all available should now be made which will be more valuable than one based upon either singly. (8) can be fully agreed with, and (9) seems of the correct order of value. I do not feel competent to discuss in detail (10) and, as said, (11) can only be when all my own data have been more fully studied. But of special interest is the statement that at the height of 82-85 km. there is a boundary of division of two predominant systems of air currents.

"This remarkable boundary is characterized according to the data on the velocity and radiation of meteors (Fedynsky and Stanjukowitsch); E. Öpik, *H.*

C. O., **40**, 549-600, 1937; and also from the character of the bands of nitrogen in the spectra of aurora borealis (Vegard), by a rapid increase in temperature. The uneven increase in temperature corresponds to the existence of an arrestive layer between the two zones, which is but rarely broken by vertical currents, as has been established by Keppen and others (*M.C.K.*, 374, 1938) with relation to troposphere inversions."

The second paper will be reserved for review to a later occasion as it is desired to publish other A.M.S. radiants recently derived from the 1939 observations. It will be noted that, with this set, all the A.M.S. serial numbers from 1 to 1777 have been filled without gaps. I hope to be able to reduce radiants for past years somewhat more rapidly in the near future, as I am no longer wasting time on maps which, at a glance, show most inferior plotting. It should be again emphasized that good meteor plotting is *not* easy to do, one must first have an excellent knowledge of the constellations and a keen eye, and must then *observe* enough to get into and stay in good practice. Only when one is willing to do this will, as a rule, his radiants—if any—be worth publishing.

The radiants given below were derived from maps by the following persons: No. 1756-58, R. Mastel, Hibbing, Minnesota; 1759-63, C. McArthur, N. Quincy, Massachusetts; 1764, C. P. Olivier, Flower Observatory, Pennsylvania; 1765-68, J. J. Neale, New Haven, Connecticut; 1769-1777 and 1951-52, R. M. Dole, Cape Elizabeth, Maine. The bracketed right ascension by No. 1764 is due to the fact that the meteors were so distributed that the declination of the radiant could be determined with much accuracy while the right ascension remained uncertain.

A.M.S. No.	1900+ Date	α	δ	No. $\rightarrow$	Acc.	Remarks
1756	39 Apr. 21.79	281	+34	6-7	FG	Lyrids
1757	Aug. 12.75	47.5	+57.5	4+	F	Perseids
1758	Aug. 16.79	54	+58.8	4	G	Perseids
1759	Aug. 11.86	43	+56	7	FG	Perseids
1760	Oct. 16.86	88	+17	4	P	Orionids
1761	Oct. 18.78	89	+14	20+	G	Orionids
1762	Oct. 20.75	92	+ 9	15±	G	Orionids??
1763	Oct. 20.75	94	+17	13±	G	Orionids
1764	Oct. 19.77	(93)	+15.5	12+	G?	Orionids
1765	Apr. 21.84	279	+32	5	F	Lyrids
1766	Oct. 19.76	90	+14	5-8	F	Orionids
1767	Oct. 19.76	90	+44	5	G	
1768	Oct. 20.78	91.8	+14.2	8	VG	Orionids
1769	Apr. 20.8	274	+40.5	10-12	G	Lyrids
1770	Aug. 10.75	43.1	+54.8	45±	VG	Perseids
1771	Aug. 10.75	10	+42	5	F	
1772	Aug. 12.79	44.5	+54.5	32	G	Perseids
1773	Oct. 20.86	90.3	+14.5	40±	VG	Orionids
1774	Oct. 23.8	94.5	+15.0	25	VG	Orionids
1775	Nov. 16.87	149.2	+21.2	67	G	Leonids
1776	Dec. 11.70	114.9	+31.7	11	G	Geminids
1777	Dec. 12.74	115.2	+31.3	29	G	Geminids
1951	26 May 6	335.8	− 0.4	23	G	Eta Aquarids
1952	26 May 7	336.2	− 0.5	21	G	Eta Aquarids

Flower Observatory of the University of Pennsylvania, Upper Darby, Pennsylvania, 1943 March 8.

Applying Mine-Crater Formulas to Meteor Crater in Arizona

By C. C. Wylie

Formulas for the charge of explosive required to produce a crater of a given size, and for the depth of the crater, are given in "Aerial Bombardment Protection" by Wessman and Rose. These formulas, attributed to the British, are as follows:

Let

n = radius crater divided by depth of charge
L = depth charge
d = diameter crater
p = depth crater
C = charge in pounds
s = soil factor
e = explosive factor

then

$$p = (L/3)\ (2n - 1)$$

and

$$C = (s/10e)\ L^3(\sqrt{1 + n^3} - 0.41)^3.$$

A study of these formulas shows that, for a given diameter of crater, the charge can be placed relatively shallow or relatively deep, with only a small variation in the amount of the explosive. The more shallow charge makes the deeper crater, and requires the larger charge of explosive, but the change in amount of explosive and in depth of crater is very small compared with the change in depth of the charge of explosive. This means that where the depth of the charge is not given, an estimated figure can be adopted for determining the amount of explosive, and, even if it happens to be considerably in error, little error will be introduced into the figure for the charge of explosive needed.

The formulas show also that, for a given shape of crater, the charge required varies as the volume. To understand this, the volume of the gases produced by the explosion will bear the same relation to the volume of the crater in the large crater as in the small. At the time of the explosion of a "common" or "undercharged" mine, most of the shattered rock is held down by the weight of the material above, and being lifted only a little is left in the crater. But the upper layers are carried off by the outrushing gases, the velocity of these overflowing gases, even well outside the rim, being sufficient to carry along large pieces of rock. If the mine is sufficiently "overcharged," all of the rock above the explosive, and indeed more, is thrown out of the crater.

Let us now apply these formulas to the craters referred to in "Calculations on the Probable Mass of the Object Which Formed Meteor Crater."[1] The results are as follows:

For Meteor Crater, it is necessary to assume a depth for the explosion, that is, for the point at which the object was vaporized. From the cross-section of the crater as indicated by drillings, the object must have exploded after penetrating only a few hundred feet, or perhaps very near the surface, and near the center of the present crater. The vaporized iron, however, retained the momentum of

[1] Popular Astronomy, **51**, page 97, February, 1943.

the falling meteor (diminished some by loss of velocity), so the gases, and any unvaporized material continued to drive downward at an angle. This resulted in the fracturing of the rock to a much greater depth below the southeastern rim than at the center of the crater. We have made the calculation for the depth of the explosion as 500 feet, and also as 900 feet, the charge being little different on the two assumptions, and have adopted the figure for 500 feet.

TABLE I

Name of Crater	*Soil or Rock*	*Diameter Crater*	*Depth of Crater Actual*	*Depth of Crater Computed*	*Depth Charge*	*Amount Charge Actual*	*Amount Charge Computed*
Anglo-Iranian Oil Co.	Soft Rock[2]	100 ft.	....[3]	20 ft.	40 ft.	3,600 lbs.	7,700 lbs.
Hill No. 60	Sand and Clay	340 ft.	67 ft.	97 ft.	50 ft.[2]	70,000 lbs.	192,000 lbs.
La Boisselle	Chalk	270 ft.	70 ft.	71 ft.	52 ft.	60,000 lbs.	107,000 lbs.
Meteor Crater	Limestone Sandstone	4,000 ft.	600 ft.	1,030 ft.	900 ft.[2]	.....	216,000 T
Meteor Crater	Limestone Sandstone	4,000 ft.	600 ft.	1,170 ft.	500 ft.[2]	.....	228,000 T

[2] Assumed.

[3] The depth was given as 40 feet, but presumably the figure referred to the depth including the shattered rock, as the explosive was placed 40 feet deep. The formula does not permit a crater 100 feet in diameter and 40 feet deep.

The mine crater at La Boisselle was produced by two charges placed 60 feet apart. Perhaps the outrushing gases from the two charges met in the middle, resulting in a loss of some of the lateral motion, and a conversion of the same into a vertical motion. Comparing the computed with the observed depths of the craters, we see that for La Boisselle the agreement is good, but that is the crater for which two charges were used.

For Hill No. 60, where a single charge was used, and for Meteor Crater, the computed depth is much too great. Evidently craters produced by several tons of explosive tend to be relatively more shallow than the smaller craters on which the formula is based. The deeper craters mean more rock thrown out, so the formula has assumed the expenditure of too much energy.

To correct the computed charges for the extra computed depths, let us assume that the same amount of rock is shattered, and that the average distance moved is proportional to the depth of the crater. Neglecting the energy required to shatter the rock, and other smaller points, the work done is proportional to the depth of the crater, and the computed charge can be corrected by that factor. For Hill No. 60 the charge is reduced from 192,000 lbs. to 133,000 lbs. For Meteor Crater (500 ft. depth charge) the charge is reduced from 228,000 tons to 117,000 tons.

Assembling the revised data we have the following:

TABLE II

Crater	*Actual Charge*	*Computed Charge*	*Per cent*
Anglo-Iranian	3,600 lbs.	7,700 lbs.	47
Hill No. 60	70,000 lbs.	133,000 lbs.	52
La Boisselle	60,000 lbs.	107,000 lbs.	52
Meteor Crater	.....	117,000 tons	..

The formula gives too high a figure for the charge of explosive, even with

the arbitrary correction for depth of crater. The computed charges for these large craters are just about double the actual charge.

Applying the correction obtained from the large explosives craters to the figure computed for Meteor Crater, we find that the charge of explosive required is approximately 60,000 tons of dynamite. In the paper referred to previously, we adopted 125,000 tons of nitroglycerin as the amount of explosive required, and stated that "for conservatism we have adopted a relatively high figure as the requirement for Meteor Crater." The present investigation indicates the correctness of that statement.

University of Iowa, February 15, 1943.

Contributions of the Society for Research on Meteorites

Edited by FREDERICK C. LEONARD
Department of Astronomy, University of California, Los Angeles

President of the Society: LINCOLN LA PAZ, Department of Mathematics, Ohio State University, Columbus

Secretary of the Society: C. H. CLEMINSHAW, Griffith Observatory, Los Angeles, and Department of Astronomy, University of Southern California, Los Angeles

Some Symbols Recommended for Use in the Classification of Meteorites etc.

By FREDERICK C. LEONARD
Department of Astronomy, University of California, Los Angeles

ABSTRACT AND INTRODUCTION

In the first column of the following table are presented some symbols that the writer has found convenient in classifying meteorites *etc.* and that he would recommend to other workers. The majority of these symbols stand for various classes in the Rose-Tschermak-Brezina system of meteoritic classification[1] and are accordingly but revisions of the rather unsatisfactory symbols already in use, while a few are innovations. In the second column of the table is given in each case the corresponding old symbol[2] (if such exists) and in the third and last, the term that the preceding symbol or symbols characterize. It is recommended furthermore that all of the symbols in the forenamed system, other than those enumerated in the second column of the accompanying table, be left unchanged until such time as the whole system of classification may be revised.

SYMBOLS RECOMMENDED FOR USE IN THE CLASSIFICATION OF METEORITES ETC.

SYMBOL RECOMMENDED	OLD SYMBOL	TERM
A	S (for "Stone")	Aerolite*
Ac	Ach	Achondrite*
An	A	Angrite
D_1	D_1	Nickel-rich (or high-nickel) ataxite*
D_1b	Db	Nickel-rich ataxite, Babb's Mill group
D_1c	Dc	Nickel-rich ataxite, Cape group
D_1l	Dl	Nickel-rich ataxite, Linville group
D_1sh	Dsh	Nickel-rich ataxite, Shingle Springs group
D_2	D_2	Nickel-poor (or low-nickel) ataxite*
D_2n	Dn	Nickel-poor ataxite, Nedagolla group

Symbol Recommended	Old Symbol	Term
D_3p	Dp	Nickel-poor ataxite, La Primitiva group
D_3s	Ds	Nickel-poor ataxite, Siratik group
D_3t	Dm	Nickel-poor ataxite, Tuscon (= Muchachos) group†
H	—	Hexahedrite*
Hn	H	Normal hexahedrite
Me	—	Meteor
Mi	Met	Meteorite*
Ms	M	Mesosiderite
Msg	Mg	Mesosiderite (grahamite)
Si	I (for "Iron")	Siderite*
So	Sid	Siderolite*
Sy	Si	Siderophyre
T	—	Tektite*
x	—	Oxidized‡

*Not further classified.

†Called also "Muchachos group" (old symbol = Dm). Inasmuch as the only recorded example of this kind of ataxite is now universally known as the "Tucson" (Arizona) meteorite, "Tuscon group" (new symbol = D_3t) is obviously a more felicitous name than "Muchachos group."

‡It is proposed that the suffix "x" be appended to a symbol to signify that the material in question is oxidized; thus, Mix = oxidized meteorite, Six = oxidized siderite (*e.g.*, "iron-shale"), Px = oxidized pallasite (*e.g.*, a "meteorode"), *etc.*

Since the foregoing are symbols, rather than abbreviations, they should in general be capitalized and should not be followed by a period.

Notes

[1] See O. C. Farrington's *Meteorites*, Ch. 12, pp. 197-204, 1915; A. L. Coulson's "A Catalogue of Meteorites," Ch. 2, pp. 16-18, *Mem. Geol. Surv. India*, **75**, 1940, and the writer's paper on the classificational distribution of the meteoritic falls of the world, in *C.S.R.M., P. A.*, **51**, 44-9, 1943.

[2] As listed by Coulson, *l.c.*, n. (1), *ante*.

What Constitutes a Genuine Meteorite?

By H. H. Nininger
American Meteorite Laboratory, Denver, Colorado

A man prominent in the field of meteoritics has criticized me for labeling as "genuine meteorites" the small specimens of oxidized nickel-iron which are mounted in my little book, *A Comet Strikes the Earth*, 1942 (*v. C.S.R.M.*, **3**, 63; *P. A.*, **50**, 565, 1942). This criticism deepens my conviction that scientists generally, and even some students of meteorites, have not yet grasped the full significance of the subject with which we deal.

Meteoritics should by this time have passed beyond the elementary stage wherein mere perfection, variety, and beauty of form are considered in the selection of worth-while specimens. Today, we are interested also in the relationships, history, origin, and processes of alteration by which, on this planet, meteorites lose their identity. One of the most important problems to which students of meteorites can apply themselves at this time is the problem of the relation of meteorites to terrestrial formations. It is a sad comment upon the work of meteoriticists that, until this very moment, nothing has been definitely learned regarding meteorites in any of the geological formations other than the most recent.

It is true that ordinary collectors have never valued the meteoritic oxide found in the vicinity of the Barringer (Canyon Diablo, Arizona) Crater. However, for one who seeks knowledge concerning meteorites, this material is very important. After learning to recognize the common varieties in their better-preserved conditions, the beginning student could do no better than to acquaint himself with the appearance and other characteristics of meteoritic oxides. Certainly, some of the most important discoveries to be made in the future development of this young science will have to do with the altered remains of meteorites in the Earth's crust.

One reason why the fragments which we attached to the little book are of especial value is that they have all been most carefully selected and identified by one who has qualified himself to pass upon their genuineness by many years of laboratory investigations. *A specimen is no less genuine just because it has taken the first step in the long course of alteration which every meteorite must follow after it reaches our planet.*

In *Our Stone-Pelted Planet*, 1933, a *meteorite* is defined (p. xix) as "A mass of solid matter, too small to be considered an asteroid, either traveling through space as an unattached unit or having landed on the Earth and still retaining its identity."

[The implied criticism was for labeling iron-shale unqualifiedly as "meteorite" —not for calling it "genuine."—F.C.L.]

Progress in Excavating the Odessa, Texas, Meteorite Crater (Abstract)*

By E. H. Sellards *and* Virgil E. Barnes
Bureau of Economic Geology, University of Texas, Austin

Excavation of the Odessa, Texas, meteorite crater as an educational project was begun in September, 1939, and has been carried on continuously since that time. The excavation is being made by Federal, State, and County funds with some contributions from private sources. The Federal funds are expended through the Works Projects Administration, the State funds through the University of Texas, and the County funds through Ector County. Aside from Government agencies, the principal contributions to the work have come from the Humble Oil and Refining Company, which has made 2 magnetometer surveys. The principal results obtained to date are the following: The large meteoritic mass of the main crater lies at a depth of 164 feet from the surface. A "rock flour" stratum representing minutely shattered material arising from the impact reaches a maximum thickness of 25 feet. The débris that fell back into the main crater varies from 10 to 30 or more feet. The wind-carried dust and silt and fine sand that have settled or washed into the crater since it was formed reach a maximum of 71 feet. One supplementary crater has been found outside the rim of the main crater. The dimensions of this "craterette" are approximately 80 feet across, maximum 23 feet in depth. The meteorites of this small crater, of which there are approximately 1000, are widely scattered, forming a zone of meteorites. They rest not at the bottom of the crater, but have penetrated from a few inches to as much as 3 feet into the underlying bedrock. In addition to this small crater, the magnetometer survey has located several additional magnetic highs. These have

*An invited paper read in abstract by the Secretary at the Eighth Meeting of the Society, Flagstaff, Arizona, June, 1941. [The Editor regrets that, through an oversight, the publication of this abstract has been unduly delayed.]

not been excavated, altho work has proceeded in one of them to the point of showing that meteorites are present.

"A Spectrographic Study of Meteorites" (Review)

Above is the title of a paper by W. W. A. Johnson and Daniel P. Norman, of the New England Spectrochemical Laboratories, West Medway, Massachusetts, in *Astroph. Jour.*, **97**, 46-50, Jan., 1943. The abstract of the paper follows:

"18 meteorites were investigated spectrographically for the presence of 69 elements. 40 elements were found, 12 of which had not previously been reported by King [*Astroph. Jour.*, **84**, 507; *v.* also *C.S.R.M.*, **1**, No. 2, 21-2, 47-51; *P. A.*, **44**, 282-3, 507-11, 1936]. The spectrograms were taken by a jumping-plate technique that permitted estimates to be made of the relative volatility of the elements found, all of which, with the exception of aluminum and titanium, vaporized in the order expected from considerations of their boiling-points and abundances. No obvious grouping of these meteorites could be made on the basis of their atomic constituents. The 2 iron meteorites investigated contained less titanium than the stones, in agreement with previous chemical and spectroscopic data."

In the paper proper it is stated that "The following 69 elements (which are usually detected in qualitative spectrochemical analyses) were sought: Ag, Al, As, Au, B, Ba, Be, Bi, Ca, Cb, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Ge, Hf, Hg, Ho, In, Ir, K, La, Li, Lu, Mg, Mn, Mo, Na, Nd, Ni, Os, P, Pb, Pd, Pr, Pt, Ra, Rb, Re, Rh, Ru, Sb, Sc, Si, Sm, Sn, Sr, Ta, Tb, Te, Th, Ti, Tl, Tm, U, V, W, Yb, Yt, Zn, Zr. The elements found [in the meteorites] are listed in Table 1." These were: Ag, Al, As,* Au, Ba, Be,* Ca, Cd,* Ce,* Co, Cr, Cs, Cu, Fe, Hg,* In,* Ir,* K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Pd,* Pt,* Ru, Sb, Sc, Si, Sn, Sr, Te,* Ti, Tm,* V, Zn, Zr.* The 12 starred are the elements not previously reported by King; however, "King found 3 elements in the meteorites he studied that we [Johnson and Norman] did not find: Rb, Ga, Ge."

In addition to the 40 elements detected by Johnson and Norman and the 3 identified solely by King, the following 9 "have been found in meteorites in amounts sufficient for quantitative determination" (according to Farrington's *Meteorites*, Ch. 11, pp. 113-16, 1915): A, C, Cl, H, He, N, O, Ra, S. Hence, this latest investigation brings to a total of 52 the number of chemical elements reported up to date in meteorites; the number recorded by Farringon in 1915 (*op. cit.*) was only 29.—F.C.L.

The First Ten Years

With the present instalment of the CONTRIBUTIONS, the publications of the Society reach their decennial. In the April, 1933, issue of POPULAR ASTRONOMY (**41**, 216), appeared a 14-line notice entitled, "The Society for Research on Meteorites." That announcement marked the beginning of our publications, which have been included in every number of this journal issued since that time.—F.C.L.

Comet Notes

By G. VAN BIESBROECK

No new comets have been announced during the last month. Of the two comets at present under observation, COMET 1942*f* (WHIPPLE) has attracted a good deal of attention on account of its uncommonly long naked-eye visibility. In the beginning of February it looked as if the expected drop in brightness had

set in, the change since the end of January reaching a full magnitude by February 8, when a naked-eye estimate by the writer gave magnitude 4.8. But a week later, February 16, the comet had regained its maximum brightness at magnitude 3.8 and at the time of writing (March 8) it is yet quite conspicuous to the naked-eye at magnitude 4.3. There is thus a considerable lag in the fading of the comet, which theoretically would have set in after the end of January and proceeded at an increasing rate. It will be of interest to follow the further evolution of this comet.

It was a most unusual sight to find this comet crossing the bowl of the Dipper at the end of February. The general appearance of the comet has not changed as much as its brightness. The tail and the large coma described last month are still conspicuous.

The discoverer has extended the ephemeris until April 2. I have extrapolated it somewhat further as follows for the moonless period in April:

		α	δ
1943 April	2	12^h43^m	$+46°5$
	6	45	45.0
	10	46	43.4
	14	12 48	+41.9

By that time we may expect a considerable drop in brightness. With the increasing distance the motion slows down but the comet will still be observable all night. In the middle of April it will pass close to Cor Caroli, the brightest star in the constellation of the Hunting Dogs.

Comet 1942 *e* (Oterma) the second comet whose presence is known at this time can no longer be seen in ordinary telescopes. On March 8 I estimated the magnitude as 14 yet the comet still shows a tail-like appendage to a well-condensed small coma. Further decrease in brightness is foreseen.

No other comets are expected at this time except some very faint periodic ones whose recovery is doubtful on account of the uncertainty of their position and of their feeble luminosity.

Williams Bay, Wisconsin, March 8, 1943.

VARIABLE STARS

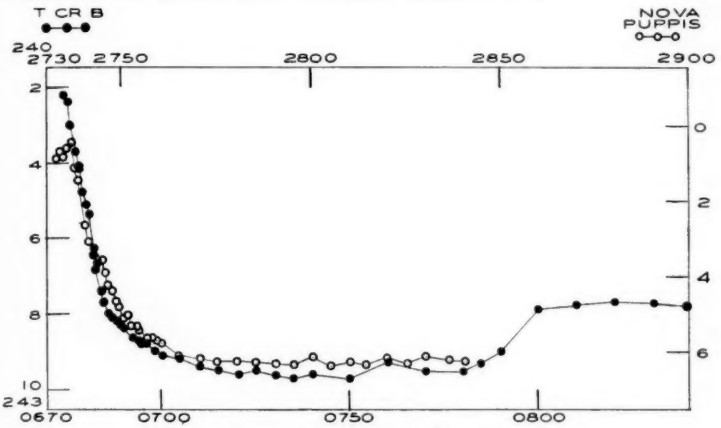
Variable Star Notes from the American Association of Variable Star Observers

By LEON CAMPBELL, Recorder

Nova Puppis, 1942, and Nova (T) Coronae Borealis, 1866. Now that Nova Puppis has been under continuous observation for several months, having decreased in that time from magnitude 0.5 at maximum to 6.3, we are able to better identify its type of variation with that of other novae. Of the large number of light curves available it appears that Nova Puppis most closely resembles that of Nova (T) Coronae Borealis, discovered in May, 1866. The latter nova attained magnitude 2.2 at maximum and in less than two months decreased to magnitude 9.6. There it remained for another month or two, after which time it gradually increased in brightness to a secondary maximum at magnitude 7.7. A year after the initial outburst T Coronae Borealis had again faded away to a brightness slightly above the tenth magnitude, and since that time it has remained, with

only slight fluctuations, at that brightness.

When the light curves of these two novae are examined the agreement is found to be remarkable. To be sure, Nova Coronae Borealis underwent a greater decrease in magnitude before it settled down after its maximum brilliance, but one can not expect too perfect coincidence in the light curves of such explosive stars as novae. The two light curves are represented in the figure, that of Nova Puppis by circles and that of Nova Coronae Borealis by dots.



LIGHT CURVES OF T CR B AND NOVA PUPPIS

Will Nova Puppis continue to follow the pattern set by Nova Coronae Borealis? If so, we may look for an increase to secondary maximum in the next few months. Nova Coronae Borealis has been identified as having existed previous to its 1866 outburst as a DM star, and its brightness after 1867 would appear to substantiate this assumption. On the other hand Nova Puppis presumably increased in light from below the seventeenth magnitude. Will Nova Puppis remain at or near its present magnitude of about the sixth, or will it, in the course of many years, slowly decrease to its pre-outburst brightness? These are questions which fire the imagination, and which time only can answer.

Observations of RV Tauri-Type Variables: One of the first major products of the work of Milton Bureau at Harvard, which began in 1938, is the recent publication of the observations of fourteen RV Tauri-type variables in *Harvard Annals*, Vol. 113, No. 1, under the joint authorship of Cecilia Payne-Gaposchkin, Virginia K. Brenton, and Sergei Gaposchkin.

The published observations, some 16,000 in number, are of course all photographic, although in the figures of light curves, extensive use has been made of contemporaneous visual observations for purposes of comparison and the determination of color indices. In general, the observations cover the years 1899 to 1942, although for TT Ophiuchi and UZ Ophiuchi they date back to 1891. Charts of the fields of each variable are shown, together with identifications and assigned photographic magnitudes of the comparison stars used.

Among the stars for which observations are presented and light curves shown are the well-known variables SS Geminorum, UU Herculis, AC Herculis,

U Monocerotis, TT Ophiuchi, AR Puppis, R Sagittae, AR Sagittarii, R Scuti, RV Tauri, and V Vulpeculae.

There is also some discussion of changes in maximum brightness, spectral changes with magnitude, interchange of minima, and of colors.

In general, the spectral changes in these stars follow the light changes. For any one star the spectral class is earliest at maximum light and latest at minimum. For R Scuti in particular the later spectra occur during both primary and secondary minima, with the "M character" making its appearance only during the deepest primary minima. The star is "bluest" at and just after primary minimum. This is shown to be the case both spectroscopically and from a study of the color differences. The peculiar change of color during primary minimum appears to produce the effect of the displacement of photographic minimum with respect to the visual, the former occurring earlier than the latter by a few days.

The mean values of the color indices for eleven of these variables discussed are, for primary maximum, +0.93; primary minimum, +0.98; secondary maximum, +0.88; secondary minimum, +1.05, or approximately one magnitude on the whole. The largest color index value is for R Scuti, for which an average value of a magnitude and a half prevails. AC Herculis shows the smallest color index, only one-half a magnitude.

A perusal of this number is quite worth while. It contains a wealth of original material, as well as sound discussion. We look forward to the appearance of further numbers of this same volume of annals.

Distribution of Variables by Types in Milky Way Fields: A recent issue of *Harvard Annals*—Vol. 109, pts. 2, 3, 4, 5, 7, and 9—presents a study of variables, old and new, found in six Milky Way Fields, as discussed by five Harvard observers. Besides listing the individual variables in each field, with discovery number, position, median brightness, and magnitude at maximum and minimum, type, and elements, where known, there are given some statistics relative to the distribution of types of variation.

A total of 663 variables is listed in these six fields, distributed as follows:

	Cluster		Cepheid		Eclipsing		Long-Period		All Others		
MWF No.	No.	%	No.	%	No.	%	No.	%	No.	%	Totals
361	76	52	1	1	24	17	19	13	24	17	144
360	80	57	1	1	18	13	17	12	25	17	141
11	80	41	3	2	28	14	38	20	44	25	193
10	14	52	0	0	5	18.5	5	18.5	3	11	27
359	43	43	1	1	9	9	12	12	34	35	99
355	23	39	0	0	17	29	6	10	13	22	59
6	316	48	6	1	101	15	97	15	143	21	663
39	1465	38	62	2	687	18	921	24	679	18	3814

Distributed throughout other Harvard publications are similar type-distributions for 33 other Milky Way Fields. The last line in the table gives the distribution statistics for all 39 regions. A comparison of the various percentages is of interest.

The Cluster-type variables persistently predominate throughout. Very few Cepheids are found, as is to be expected. There is a fair proportion of eclipsing stars and long-period variables, with all other types numbering 18 per cent of all the variables, including irregular, semiregular, short-period, unknown, novae, R Coronae Borealis, and SS Cygni stars. When the six regions are compared

with all 39 fields, the cluster-type variables exceed the average percentage by 10, and the long-period stars are 9 per cent less. Otherwise the percentages hold very well.

MWF 361 is notable for the small number of eclipsing binaries of the W Ursae Majoris type, the high percentage of semiregular variables, and one classical Cepheid with a period of 1.116 days. Another interesting star in this field is the nova, or nova-like star, X Serpentis, which was at maximum, magnitude nine, in 1903, and which since 1932, appears to show regular fluctuations between magnitudes fourteen and sixteen in a period of 275 days.

Four areas in MWF 360 were examined for nebulae where there was found a population of perhaps five nebulae per square degree down to magnitude 17.7, which suggests an absorption factor of approximately 1.3 magnitudes.

The number of variables found in MWF 11 is large, but not unduly so for galactic latitude +18 degrees. An examination of four areas in this field reveals a density of less than one galaxy per square degree down to magnitude 16.0, indicating an absorption of about three magnitudes.

In MWF 10 the observer finds a period of 195.3 days for V Corvi, instead of 126.7 days, as reported by Seliwanow. Also, this field has an unusually large number of semiregular and irregular variables when compared with the nearby field, number 360.

Observations received during January and February, 1943:

Name	January Var.	January Obs.	February Var.	February Obs.	Name	January Var.	January Obs.	February Var.	February Obs.
Bappu			35	130	Luft	2	11		
Blunck	12	12	15	15	Mason	3	3		
Bouton	38	55	39	59	Maupomé, A. S.	75	98	147	180
Chandra	66	77			Maupomé, E.			14	14
Cousins	55	107	32	96	Mayall	1	18	1	12
Dafter	5	10	9	25	Nadeau	40	51	38	50
De Kock	56	259			Palo	4	4		
Escalante	58	145	100	179	Parker			18	19
Fernald	99	154	77	196	Parks	19	19	20	20
Garneau	16	19			Peltier	52	69	109	147
Griffin			1	2	Reeves	1	2	1	2
Harris	38	38	31	31	Rosebrugh	11	49	17	57
Hartmann	119	123	128	137	Sill	47	47	12	12
Hiett	9	13			Topham			5	5
Howarth	17	31	6	6	Vohman	17	18	12	13
Kearons	68	112	37	52	Webb	8	8		
Kelly	7	12	13	15	Weber	47	47	53	53
Koons	21	27	14	16					
Labrecque	18	29			Totals 36		1667		1543

March 15, 1943.

General Notes

Dr. Carlos U. Cesco and Dr. Jorge Sahade of the Astronomical Observatory at La Plata, Argentina, have been appointed volunteer rearch assistants at the McDonald and Yerkes Observatories and will arrive in the United States in the latter part of the summer. The Argentinian astronomers are being sent by their government to investigate methods in astronomy and astrophysics now in use at the Yerkes and McDonald Observatories. Mr. Guido Münch Panagua of

the National Observatory of Mexico, at Tacubaya, has been appointed assistant at the Yerkes and McDonald Observatories for one year. He will replace one of the assistants who has left to join the armed forces.

March 16, 1943.

Dr. Henry Norris Russell, Professor of Astronomy in Princeton University, delivered a public lecture on the subject, "Science Looks at God," at the University of California, Los Angeles, on March 3, 1943. The lecture was given under the auspices of the University Committee on Lectures, Music, and Drama.

The Rittenhouse Astronomical Society held a joint meeting with the Franklin Institute on Wednesday, March 3, 1943. The address was given by Forest Ray Moulton, Ph.D., permanent secretary of the American Association for the Advancement of Science, on "Newton, His Influence on Science and Philosophy."

Moon Phases Correlated with Iris Blooms

Dr. Knight Dunlap, Los Angeles, California, has come to the conclusion, after observations extending over more than a year, that there is a definite correlation between the phases of the Moon and the blossoming periods of South African irises. He states that the blooms are plentiful during the first and last quarters of the Moon and that the plants stand bare-stemmed or nearly so during new and full Moon.

Many attempts have been made to discover a connection between terrestrial phenomena and the solar and lunar cycles, but few have led to such definite results as this.

The Aurora of February 25, 1943

The first auroral display of any magnitude visible here in many months was observed on the evening of February 25, 1943.

Shortly after sunset it became certain that an aurora was becoming visible above the northern horizon. By 8:30 P.M., E.W.T., a pronounced arch of considerable width was evident and here and there thin wavering streamers commenced to shoot up from the main body of light. In contrast to the usual progress of auroral displays the number of these streamers did not increase and indeed the whole display was rendered notable by the absence of these familiar auroral phenomena.

At 10:00 P.M. the aurora was visible as a broad curved band of softly glowing apple-green light, extending across the entire northern horizon. At this time the upper limit of the arch was well above Polaris. From time to time a scarcely perceptible *waving*, similar to the action of a heavy curtain in a light breeze, could be seen. Not more than six streamers could be detected at this time. The brighter stars of Ursa Major were just visible through the glowing haze. Between the lower edge of the arch and the horizon was an area of intensely black sky, approximately 10 degrees in width, through which no stars were visible.

From 11:00 P.M. on, the auroral activity began to diminish and the brightness of the arch to wane, with occasional resurgence of brilliance until at midnight there were only scattered patches of faint hazy light. Low in the north was a bank of heavy dark clouds into which the last vestiges of the aurora seemed to be retreating.

Magnetic disturbances were not pronounced during or after this display and as far as could be determined, in this area at least, high frequency radio signals

were not unduly affected. Operators of teletype and telegraph lines reported that they had experienced no difficulties in carrying on their normal activities.

This is the first aurora that I have observed under "dim-out" conditions and the shading of the street lights has certainly improved conditions for auroral observers. While the primary cause for the institution of the "dim-out" regulation is to be deplored, astronomers would assuredly benefit if this condition were to be made permanent.

LEWIS J. BOSS.

Warwick Neck, Rhode Island, February 27, 1943.

S.S. Maria Mitchell

The California Shipbuilding Corporation at Terminal Island recently launched its 147th ship which was named the *S.S. Maria Mitchell* in honor of the well-known American astronomer. Mrs. John Kiely, wife of the superintendent of the company's hull and yard department officiated as sponsor at the launching.

Launching of the S.S. Simon Newcomb, Calship No. 158

Another ship bearing the name of a well-known American astronomer has recently been launched by the California Shipbuilding Corporation.

Friday, March 26, 1943, 12:30 A.M.

Sponsor: Mrs. Walter H. Adams,[1] wife of Colonel Adams, State Adviser on occupational Deferments for Southern California Selective Service System.

Matron of Honor: Mrs. Albert G. Berry.[2]

Master of Ceremonies: John D. Burton, Employee Relations Manager, California Shipbuilding Corporation.

SIMON NEWCOMB (1835-1909), astronomer.

Simon Newcomb was born in Wallace, Nova Scotia, on March 12, 1835. His father was an itinerant school teacher from New England. When Newcomb was 18, he left for the United States, working his passage aboard a ship to Salem, Mass. From there he went to Maryland, teaching school for several years.

In 1857 he became a computer in the *Nautical Almanac* office at Harvard. He attended the Lawrence Scientific School of Harvard, graduating in 1858 with the degree of B.Sc. In 1861 he was commissioned professer of mathematics in the United States Navy, in which service he continued at the Naval Observatory and the Nautical Almanac Office until his retirement in 1897 with the naval rank of captain.

For his achievements in astronomy, Newcomb was elected to the principal academies and societies of the world. He wrote many scientific articles which appeared in astronomical journals in America and abroad. He took a prominent part in procuring the 26-inch telescope of the United States Naval Observatory and in the foundation of Lick Observatory.

On August 4, 1863, he married Mary Caroline Hassler, daughter of Dr. C. A. Hassler, United States Navy. They had three daughters.

Newcomb died on July 11, 1909, at Washington, D. C.

Data regarding *S.S. Simón Newcomb*. Keel laid: February 27, 1943. Launched: March 26, 1943. Days on ways: 27. Ships launched to date: 158. Ships delivered to date: 150.

[1] Of 1633 Ard Eevin Avenue, Glendale, Calif.

[2] Of 744 South Beacon Street, Los Angeles, Calif.

Book Reviews

Map Reading and Avigation: An Introduction, by R. M. Field and H. T. Stetson. (D. Van Nostrand Co., Inc., New York, 1942, 129 pp. $2.50.)

Part I deals with Map Reading; Part II of exactly equal length, with "Avigation"—principally with Celestial Navigation. It is understood that Part I was written by Professor Field and Part II by Professor Stetson.

Part I includes a stimulating outline of physiographic information concerning North America. Any experienced air navigator can read this with profit, because even a little acquaintance with land forms will add interest to his flights, and may serve occasionally to help indentify his position. If a forced landing should be necessary, familiarity with the type of country underneath is an aid to selection of an emergency landing ground. Many illustrative photographs are included. Contour maps of selected regions are compared with oblique and vertical photographs of models of the same regions, or with actual airplane photographs. These reproductions are excellent.

Part II also includes many well-done illustrations. Meridian altitudes are described with more completeness than usual. Excerpts from the *Air Almanac* and from *H. O.* No. 214 are conveniently appended, and this book serves a student who wishes to learn this important method of solving the "astronomical triangle."

Part II is far from being a general outline of Air Navigation; phases other than celestial navigation are passed over very rapidly. The reviewer desires to interpolate an objection to the use of the term "Avigation." Not on etymological grounds; the word is satisfactory in that respect; but because Air Navigation and Marine Navigation are so closely related that a new word is not needed. There is very little in Part II which is not equally useful for the sea.

Both parts of the book are too brief to serve as texts for a term's college course. The point of view—as with much recent civilian and Army training in Air Navigation—is confined pretty much to the United States. But for the sake of the unique qualities indicated above, the book makes a worthwhile addition to any navigation shelf.

JOHN Q. STEWART.

Princeton University Observatory, March 10, 1943.

Publications Received.—The publishers of POPULAR ASTRONOMY hereby acknowledge the receipt of the following named publications and express their great appreciation of the courtesy shown on the part of those who have sent them.

Contributions from the Perkins Observatory:

No. 17. "Magnitudes and Colors in the Globular Cluster Messier 12 and Selected Area 108," by J. J. Nassau and J. A. Hynek.

No. 18. "The Composite Spectrum of ζ Tauri," by J. A. Hynek and O. Struve.

Reprints from the Perkins Observatory:

No. 28. "Observation of the Brightness of Comets," by N. T. Bobrovnikoff (1941).

No. 29. "Observation of the Brightness of Comets," by N. T. Bobrovnikoff (1942).

No. 30. "Edmond Halley, 1656-1742," by N. T. Bobrovnikoff.

No. 31. "Physical Theory of Comets in the Light of Spectroscopic Data," by N. T. Bobrovnikoff.